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(54) Title: JET PUMP
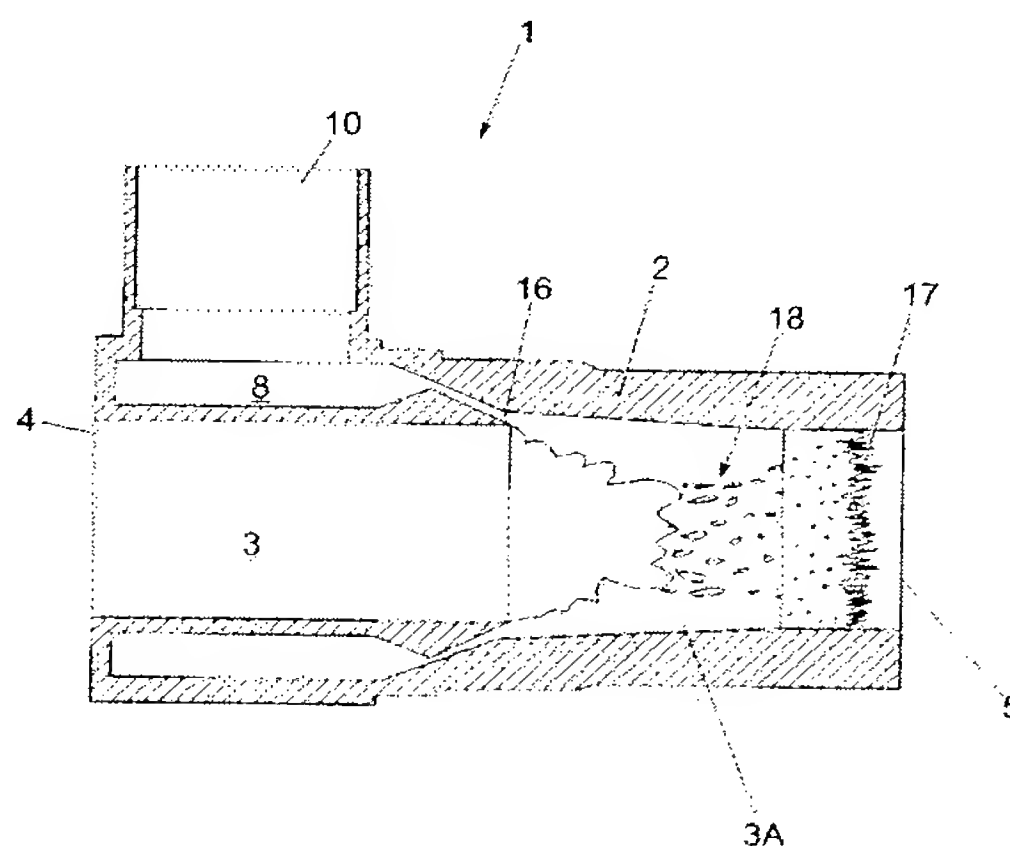
(57) Abstract: A fluid mover (1) includes a hollow body (2) provided with a straight-through passage (3) of substantially constant cross section with an inlet end (4) an outlet end (5) for the entry and discharge respectively of a working fluid. A nozzle (16) substantially circumscribes and opens into the passage (3) intermediate the inlet (4) and outlet (5) ends. An inlet (10) communicates with the nozzle (16) for the introduction of a transport fluid and a mixing chamber (3A) is formed within the passage (3) downstream of the nozzle (16). The nozzle internal geometry and the bore profile immediately upstream of the nozzle exit are disposed and configured to optimise the energy transfer between the transport fluid and working fluid. In use, through the introduction of transport fluid, the working fluid or fluids are atomised to form a dispersed vapour/droplet flow regime with locally supersonic flow conditions within a pseudo-vena contracta, resulting in the creation of a supersonic condensation shock wave (17) within the downstream mixing chamber (3A) by the condensation of the transport fluid. Methods of moving and processing fluids using the fluid mover are also disclosed.

JET PUMP

1	This invention relates to a method and apparatus for
2	moving a fluid.
3	
4	The present invention has reference to improvements
5	to a fluid mover having a number of practical
6	applications of diverse nature ranging from marine
7	propulsion systems to pumping applications for
8	moving and/or mixing fluids and/or solids of the
9	same or different characteristics. The present
10	invention also has relevance in the fields inter
11	alia of heating, cooking, cleaning, aeration, gas
12	fluidisation, and agitation of fluids and
13	fluids/solids mixtures, particle separation,
14	classification, disintegration, mixing,
15	emulsification, homogenisation, dispersion,
16	maceration, hydration, atomisation, droplet
17	production, viscosity reduction, dilution, shear
18	thinning, transport of thixotropic fluids and
19	pasteurisation.

1

2   More particularly the invention is concerned with

3   the provision of an improved fluid mover having

4   essentially no moving parts.

5

6   Ejectors are well known in the art for moving

7   working or process fluids by the use of either a

8   central or an annular jet which emits steam into a

9   duct in order to move the fluids through or out of

10   appropriate ducting or into or through another body

11   of fluid. The ejector principally operates on the

12   basis of inducing flow by creating negative

13   pressure, generally by the use of the venturi

14   principle. The majority of these systems utilise a

15   central steam nozzle where the induced fluid

16   generally enters the duct orthogonally to the axis

17   of the jet, although there are exceptions where the

18   reverse arrangement is provided. The steam jet is

19   accelerated through an expansion nozzle into a

20   mixing chamber where it impinges on and is mixed

21   with working fluid. The mixture of working fluid

22   and steam is accelerated to higher velocities within

23   a downstream convergent section prior to a divergent

24   section, e.g. a venturi. The pressure gradient

25   generated in the venturi induces new working fluid

26   to enter the mixing chamber. The energy transfer

27   mechanism in most steam ejector systems is a

28   combination of momentum, heat and mass transfer but

29   by varying proportions. Many of these systems

30   employ the momentum transfer associated with a

31   converging flow, while others involve the generation

32   of a shock wave in the divergent section. One of

1   the major limitations of the conventional

2   convergent/divergent systems is that their

3   performance is very sensitive to the position of the

4   shock wave which tends to be unstable, easily moving

5   away from its optimum position. It is known that if

6   the shock wave develops in the wrong place within

7   the convergent/divergent sections, the relevant unit

8   may well stall. Such systems can also only achieve

9   a shock wave across a restricted section.

10

11 Furthermore, for systems which employ a central

12 steam nozzle, the throat dimension restriction and

13 the sharp change of direction affecting the working

14 fluid presents a serious limitation on the size of

15 any particulate throughput and certainly any rogue

16 material that might enter the system could cause

17 blockage.

18

19 An improved fluid mover is described in our

20 International Patent Application No

21 PCT/GB2003/004400 in which the interaction of a

22 working fluid or fluids and a transport fluid

23 projected from a nozzle arrangement provides

24 pumping, entrainment, mixing, heating,

25 emulsification, and homogenization etc. of the

26 working fluid or fluids. The fluid mover introduces

27 an annular supersonic jet of transport fluid,

28 typically steam, into a relatively large diameter

29 straight through hollow passage. Through a

30 combination of momentum transfer, high shear, and

31 the generation of a condensation shock wave, the

32 high velocity steam induces and acts upon the

4

1   working fluid passing through the centre of the

2   hollow body.

3

4   PCT/GB2003/004400 describes that the transport fluid

5   is preferably a condensable fluid and may be a gas

6   or vapour, for example steam, which may be

7   introduced in either a continuous or discontinuous

8   manner. At or near the point of introduction of the

9   transport fluid, for example immediately downstream

10   thereof, a pseudo-vena contracta or pseudo

11   convergent/divergent section is generated, akin to

12   the convergent/divergent section of conventional

13   steam ejectors but without the physical constraints

14   associated therewith since the relevant section is

15   formed by the effect of the steam impacting upon the

16   working or process fluid. Accordingly the fluid

17   mover is more versatile than conventional ejectors

18   by virtue of a flexible fluidic internal boundary

19   described by the pseudo-vena contracta. The

20   flexible boundary lies between the working fluid at

21   the centre and the solid wall of the unit, and

22   allows disturbances or pressure fluctuations in the

23   multi phase flow to be accommodated better than for

24   a solid wall. This advantageously reduces the

25   supersonic velocity within the multi phase flow,

26   resulting in better droplet dispersion, increasing

27   the momentum transfer zone length, thus producing a

28   more intense condensation shock wave.

29

30   PCT/GB2003/004400 further discloses that the

31   positioning and intensity of the shock wave is

32   variable and controllable depending upon the

1   specific requirements of the system in which the
2   fluid mover is disposed. The mechanism relies on a
3   combination of effects in order to achieve its high
4   versatility and performance, notably heat, momentum
5   and mass transfer which gives rise to the generation
6   of the shock wave and also provides for shearing of
7   the working fluid flow on a continuous basis by
8   shear dispersion and/or dissociation. Preferably
9   the nozzle is located as close as possible to the
10 projected surface of the working fluid in practice
11 and in this respect a knife edge separation between
12 the transport fluid or steam and the working fluid
13 stream is of advantage in order to achieve the
14 requisite degree of interaction. The angular
15 orientation of the nozzle with respect to the
16 working fluid stream is of importance and may be
17 shallow.
18
19 Further, PCT/GB2003/004400 discloses that the or
20 each transport fluid nozzle may be of a convergent-
21 divergent geometry internally thereof, and in
22 practice the nozzle is configured to give the
23 supersonic flow of transport fluid within the
24 passage. For a given steam condition, i.e. dryness,
25 pressure and temperature, the nozzle is preferably
26 configured to provide the highest velocity steam
27 jet, the lowest total pressure drop and the highest
28 static enthalpy between the steam chamber and the
29 nozzle exit. The nozzle is preferably configured to
30 avoid any shock in the nozzle itself. For example
31 only, and not by way of limitation, an optimum area
32 ratio for the nozzle, namely exit area: throat area,

1   lies in the range 1.75 and 7.5, with an included
2   angle of less than 9°.
3
4   The or each nozzle is conveniently angled towards
5   the working fluid flow and also faces generally
6   towards the outlet of the fluid mover. This helps
7   penetration of the working fluid by the transport
8   fluid, which may help shear or thermal dispersion of
9   the working fluid. This may also prevent both
10   kinetic energy dissipation on the wall of the
11   passage and premature condensation of the steam at
12   the wall of the passage, where an adverse
13   temperature differential prevails. The angular
14   orientation of the nozzles is selected for optimum
15   performance which is dependent inter alia on the
16   nozzle orientation and the internal geometry of the
17   mixing chamber. Further the angular orientation of
18   the or each nozzle is selected to control the
19   pseudo-convergent/divergent profile, the pressure
20   profile within the mixing chamber, the enthalpy
21   addition and the condensation shock wave intensity
22   or position in accordance with the pressure and flow
23   rates required from the fluid mover. Moreover, the
24   creation of turbulence, governed inter alia by the
25   angular orientation of the nozzle, is important to
26   achieve optimum performance by dispersal of the
27   working fluid to a vapour-droplet phase in order to
28   increase acceleration by momentum transfer. This
29   aspect is of particular importance when the fluid
30   mover is employed as a pump. For example, and not
31   by way of limitation, in the present invention it
32   has been found that an angular orientation for the

1   or each nozzle may lie in the range 0 to 30° with
2   respect to the flow direction of the working fluid.
3
4   A series of nozzles with respective mixing chamber
5   sections associated therewith may be provided
6   longitudinally of the passage and in this instance
7   the nozzles may have different angular orientations,
8   for example decreasing from the first nozzle in a
9   downstream direction. Each nozzle may have a
10   different function from the other or others, for
11   example pumping, mixing, disintegrating, and may be
12   selectively brought into operation in practice.
13   Each nozzle may be configured to give the desired
14   effects upon the working fluid. Further, in a
15   multi-nozzle system by the introduction of the
16   transport fluid, for example steam, phased heating
17   may be achieved. This approach may be desirable to
18   provide a gradual heating of the working fluid.
19
20   An object of the present invention is to improve the
21   performance of the fluid mover by enhancing the
22   energy transfer mechanism between the high velocity
23   transport fluid and the working fluid. This
24   improves the performance of the fluid mover having
25   essentially no moving parts having an improved
26   performance than fluid movers currently available in
27   the absence of any constriction such as is
28   exemplified in the prior art recited in the
29   aforementioned patent.
30
31   According to a first aspect of the present invention
32   a fluid mover includes a hollow body provided with a

1 straight-through passage of substantially constant
2 cross section with an inlet at one end of the
3 passage and an outlet at the other end of the
4 passage for the entry and discharge respectively of
5 a working fluid, a nozzle substantially
6 circumscribing and opening into said passage
7 intermediate the inlet and outlet ends thereof, an
8 inlet communicating with the nozzle for the
9 introduction of a transport fluid, a mixing chamber
10 being formed within the passage downstream of the
11 nozzle, the nozzle internal geometry and the bore
12 profile immediately upstream of the nozzle exit
13 being so disposed and configured to optimise the
14 energy transfer between the transport fluid and
15 working fluid that in use through the introduction
16 of transport fluid the working fluid or fluids are
17 atomised to form a dispersed vapour/droplet flow
18 regime with locally supersonic flow conditions
19 within a pseudo-vena contracta, resulting in the
20 creation of a supersonic condensation shock wave
21 within the downstream mixing chamber by the
22 condensation of the transport fluid.
23
24 The transport fluid is preferably a condensable
25 fluid and may be a gas or vapour, for example steam,
26 which may be introduced in either a continuous or
27 discontinuous manner.
28
29 According to a second aspect of the present
30 invention a fluid mover of the kind described in our
31 aforementioned patent application, includes a hollow
32 body provided with a straight-through passage of

9

1   substantially constant cross section with an inlet

2   at one end of the passage and an outlet at the other

3   end of the passage for the entry and discharge

4   respectively of a working fluid, a nozzle

5   substantially circumscribing and opening into said

6   passage intermediate the inlet and outlet ends

7   thereof, an inlet communicating with the nozzle for

8   the introduction of steam, a mixing chamber being

9   formed within the passage downstream of the nozzle,

10   the nozzle internal geometry and the bore profile

11   immediately upstream of the nozzle exit being so

12   disposed and configured to optimise the energy

13   transfer between the steam and working fluid that in

14   use through the introduction of steam the working

15   fluid or fluids are atomised to form a dispersed

16   vapour/droplet flow regime with locally supersonic

17   flow conditions within a pseudo-vena contracta,

18   resulting in the creation of a supersonic

19   condensation shock wave within the downstream mixing

20   chamber by the condensation of the steam.

21

22   The nozzle may be of a form to correspond with the

23   shape of the passage and thus for example a circular

24   passage would advantageously be provided with an

25   annular nozzle circumscribing it. The term

26   'annular' as used herein is deemed to embrace any

27   configuration of nozzle or nozzles that

28   circumscribes the passage of the fluid mover, and

29   encompasses circular, irregular, polygonal and

30   rectilinear shapes of nozzle. The term

31   "circumscribing" or "circumscribes" as used herein

32   is deemed to embrace not only a continuous nozzle

1   surrounding the passage, but also a discontinuous

2   nozzle having two or more nozzle outlets partially

3   or entirely surrounding the passage.

4

5   The or each nozzle may be of a convergent-divergent

6   geometry internally thereof, and in practice the

7   nozzle is configured to give the supersonic flow of

8   transport fluid within the passage. For a given

9   steam condition, i.e. dryness, pressure and

10   temperature, the nozzle is preferably configured to

11   provide the highest velocity steam jet, the lowest

12   total pressure drop and the highest enthalpy between

13   the steam chamber and nozzle exit.

14

15   The condensation profile in the mixing chamber

16   determines the expansion ratio profile across the

17   nozzle. With relatively low working fluid

18   temperatures condensation is dominant, and the exit

19   pressure of the transport fluid nozzle is low. The

20   exit pressure of the transport fluid nozzle is

21   higher when the bulk temperature of the working

22   fluid is higher.

23

24   According to a third aspect of the present invention

25   a method of moving a working fluid includes

26   presenting a fluid mover to the working fluid,

27   the mover having a straight-through passage of

28   substantially constant cross section,

29   applying a substantially circumscribing stream

30   of a transport fluid to the passage through an

31   annular nozzle,

11

1   atomising the working fluid to form a dispersed
2   vapour and droplet flow regime with locally
3   supersonic flow conditions,
4   generating a supersonic condensation shock wave
5   within the passage downstream of the nozzle by
6   condensation of the transport fluid,
7   inducing flow of the working fluid through the
8   passage from an inlet to an outlet thereof, and
9   modulating the condensation shock wave to vary
10   the working fluid discharge from the outlet.
11
12   Preferably the modulating step includes modulating
13   the intensity of the condensation shock wave..
14   Alternatively or additionally the modulating step
15   includes modulating the position of the condensation
16   shock wave.
17
18   The bore profile immediately upstream of the nozzle
19   is preferably configured to encourage working fluid
20   atomisation. Preferably an instability in working
21   fluid flow is introduced immediately upstream of the
22   nozzle.
23
24   The or each nozzle is preferably optimally
25   configured to operate with a particular working
26   fluid, upstream wall contour profile and mixing
27   chamber geometry. The nozzles, upstream wall
28   contour profile and mixing chamber combination are
29   configured to encourage working fluid atomisation
30   creating a vapour/droplet mixed flow with local
31   supersonic flow conditions. This encourages the
32   formation of the downstream condensation shock wave,

1   by enhancing local turbulence, pressure gradient and

2   the momentum and heat transfer rate between the

3   transport and working fluids by maximising surface

4   contact between the fluids.

5

6   The or each nozzle is preferably configured to

7   operate with a particular working fluid, upstream

8   wall contour profile and mixing chamber to provide

9   an optimum nozzle exit pressure. Initial pressure

10   recovery due to transport fluid deceleration,

11   coupled with the downstream pressure drop due to

12   condensation, is used to ensure the nozzle expansion

13   ratio is adjusted to enhance atomisation of the

14   working fluid and momentum transfer.

15

16   The exit velocity from the or each nozzle may be

17   controlled by varying the transport fluid supply

18   pressure, the expansion ratio of the nozzle and the

19   condensation profile in the immediate region of the

20   mixing chamber. The nozzle exit velocities may be

21   controlled to enhance Momentum Flux Ratios M in the

22   immediate region of the mixing chamber, where M is

23   defined by the equation

24
$$M \equiv \frac{\left(\rho_s \times U_s^{\,2}\right)}{\left(\rho_f \times U_f^{\,2}\right)}$$

25

26   where ρ = Fluid density

27   U = Fluid velocity

28   Subscript s represents transport fluid

29   Subscript f represents working fluid

30

1   In the present invention it has been found that an
2   optimum Momentum Flux Ratio M for the or each nozzle
3   lies in the range $2 \leq M \leq 70$. For example, when using
4   steam as the transport fluid, with a working fluid
5   with a high water content, M for the or each nozzle
6   lies in the range $5 \leq M \leq 40$.
7
8   The or each nozzle is configured to provide the
9   desired combination of axial, radial and tangential
10 velocity components. It is a combination of axial,
11 radial and tangential components which influence the
12 primary turbulent break-up (atomisation) of the
13 working fluid flow and the pressure gradient.
14
15 The interaction between the transport fluid and the
16 working fluid, leading to the atomisation of the
17 working fluid, is enhanced by flow instability.
18 Instability enhances the droplet stripping from the
19 contact surface of the core flow of the working
20 fluid. A turbulent dissipation layer between the
21 transport and working fluids is both fluidically and
22 mechanically (geometry) encouraged ensuring rapid
23 fluid core dissipation. The pseudo-vena contracta
24 is a resultant aspect of this droplet atomisation
25 region.
26
27 The internal walls of the flow passage upstream of
28 the or each nozzle may be contoured to provide a
29 combination of axial, radial and tangential velocity
30 components of the outer surface of the working fluid
31 core when it comes into contact with the transport
32 fluid. It is a combination of these velocity

1   components which inter alia influence the primary
2   turbulent break-up (atomisation) of the working
3   fluid and the pressure gradient when it comes into
4   contact with the transport fluid.
5
6   Under optimum operating conditions the
7   disintegration or atomisation of the working fluid
8   core is extremely rapid. The disintegration across
9   the whole bore will typically take place in the
10 mixing chamber within, but not limited to, a
11 distance approximately equivalent to 0.66D
12 downstream of the nozzle exit. Under different non-
13 optimised operating conditions disintegration across
14 the whole bore of the mixing chamber, may still
15 occur within, but not limited to, a distance
16 equivalent to 1.5D downstream of the nozzle exit,
17 where D is the nominal diameter of the bore through
18 the centre of the fluid mover.
19
20 Recirculation occurs in the flow. The
21 recirculation is particularly dominant where
22 tangential velocity components of the transport
23 fluid are present. The radial pressure gradients
24 created within the mixing chamber are responsible
25 for this flow phenomenon which encourages complete
26 and rapid flow dispersion characteristics across the
27 bore.
28
29 This effect is also created when the pseudo-vena
30 contracta is partially established, i.e. vapour-
31 droplet flow is dominant along the mixing chamber
32 boundary. The localised pressure gradient draws

15

1   flow outwards, causing a region downstream of the

2   transport fluid nozzle exit, typically between 1

3   diameter and 2 diameters downstream, where the axial

4   flow component of the working fluid stagnates and

5   may even reverse briefly on the centre-line, i.e.

6   the centre of the flow region.

7

8   Recirculation has particular benefits in some

9   applications such as emulsification.

10

11   A series of nozzles with respective mixing chamber

12   sections associated therewith may be provided

13   longitudinally of the passage and in this instance

14   the nozzles may have different angular orientations,

15   for example decreasing from the first nozzle in a

16   downstream direction. Each nozzle may have a

17   different function from the other or others, for

18   example pumping, mixing, disintegrating or

19   emulsifying, and may be selectively brought into

20   operation in practice. Each nozzle may be

21   configured to give the desired effects upon the

22   working fluid. Further, in a multi-nozzle system by

23   the introduction of the transport fluid, for example

24   steam, phased heating may be achieved. This

25   approach may be desirable to provide a gradual

26   heating of the working fluid, enhanced atomisation,

27   pressure gradient profiling or a combinatory effect,

28   such as enhanced emulsification.

29

30   In addition the internal walls of the flow passage

31   immediately upstream of the or each nozzle exit may

32   be contoured to provide different degrees of

1 turbulence to the working fluid prior to its

2 interaction with the transport fluid issuing from

3 the or each nozzle.

4

5 The mixing chamber geometry is determined by the

6 desired and projected output performance and to

7 match the designed transport fluid conditions and

8 nozzle geometry. In this respect it will be

9 appreciated that there is a combinatory effect as

10 between the various geometric features and their

11 effect on performance, namely there is interaction

12 between the various design and performance

13 parameters having due regard to the defined function

14 of the fluid mover.

15

16 According to a fourth aspect of the present

17 invention a method of processing a working fluid

18 includes

19   presenting a fluid mover to the working fluid,

20 the fluid mover having a straight-through passage of

21 substantially constant cross section,

22   applying a substantially circumscribing stream

23 of a transport fluid to the passage through an

24 annular nozzle,

25   atomising the working fluid to form a dispersed

26 vapour and droplet flow regime with locally

27 supersonic flow conditions,

28   generating a supersonic condensation shock wave

29 within the passage downstream of the nozzle by

30 condensation of the transport fluid, the position of

31 the condensation shock wave remaining substantially

32 constant under equilibrium flow,

17

1   inducing flow of the working fluid through the
2   passage from an inlet to an outlet thereof, and
3   changing the position of the condensation shock
4   wave to vary the working fluid discharge from the
5   outlet.
6
7   Changing the position of the condensation shock wave
8   is preferably achieved by varying at least one of a
9   group of parameters, the group of parameters
10   including the inlet temperature of the working
11   fluid, the flow rate of the working fluid, the inlet
12   pressure of the working fluid, the outlet pressure
13   of the working fluid, the flow rate of a fluid
14   additive added to the working fluid, the inlet
15   pressure of a fluid additive added to the working
16   fluid, the outlet pressure of a fluid additive added
17   to the working fluid, the temperature of a fluid
18   additive added to the working fluid, the angle of
19   entry of the transport fluid to the passage, the
20   inlet temperature of the transport fluid, the flow
21   rate of the transport fluid, the inlet pressure of
22   the transport fluid, the internal dimensions of the
23   passage downstream of the nozzle, and the internal
24   dimensions of the passage upstream of the nozzle.
25
26   The term straight-through when used to describe a
27   passage encompasses any passage having a clear flow
28   path therethrough, including curved passages.
29
30   The fluid additive may be gaseous or liquid. The
31   fluid additive is not an essential element of the
32   invention, but in certain circumstances may be

1   beneficial. The fluid additive may comprise a
2   powder in dry form or suspended in a fluid.
3
4   The parameter varying step may include switching
5   between a plurality of transport fluids or between a
6   plurality of fluid additives.
7
8   The improvements of the present invention may be
9   employed to the fluid mover of the aforementioned
10 patent, and enhance its use in a variety of
11 applications as disclosed in the aforementioned
12 patent. These applications range from use as a
13 fluid processor, including pumping, mixing, heating,
14 homogenising etc, to marine propulsion, where the
15 mover is submersed within a body of fluid, namely
16 the sea or lake or other body of water. In its
17 application to fluid processing a variety of working
18 fluids may be processed and may include liquids,
19 liquids with solids in suspension, slurries, sludges
20 and the like. It is an advantage of the straight-
21 through passage of the mover that it can accommodate
22 material that might find its way into the passage.
23
24 The fluid mover of the present invention may also be
25 used for enhanced mixing, dispersion or hydration
26 and again the combination of the shearing mechanism,
27 droplet formation and presence of the condensation
28 shock wave provides the mechanism for achieving the
29 desired result. In this connection the fluid mover
30 may be used for mixing one or more fluids, one or
31 more fluids and solids in particulate form, for
32 example powders. The fluids may be in liquid or

1   gaseous form. It has been found that the use of the

2   present invention when mixing liquid with a powder

3   of particulate form results in a homogeneous

4   mixture, even when the powder is of material which

5   is difficult to wet, for example Gum Tragacanth

6   which is a thickening agent.

7

8   The treatment of the working fluid, for example

9   heating, dosing, mixing, dispersing, emulsifying etc

10 may occur in batch mode using at least one fluid

11 mover or by way in an in-line or continuous

12 configuration using one or more fluid movers as

13 required.

14

15 A further use to which the present invention may be

16 put is that of emulsification which is the formation

17 of a suspension by mixing two or more liquids which

18 are not soluble in each other, namely small droplets

19 of one liquid (inner phase) are suspended in the

20 other liquid(s) (outer phase). Emulsification may

21 be achieved in the absence of surfactant blends,

22 although they may be used if so desired. In

23 addition, due to the straight through nature of the

24 invention, there is no limitation on the particle

25 size that can be handled, allowing particle sizes up

26 to the bore size of the unit to pass through whilst

27 emulsification is taking place.

28

29 The fluid mover may also be employed for

30 disintegration, for example in the paper industry

31 for disintegration of paper pulp. A typical example

32 would be in paper recycling, where waste paper or

20

1   broken pieces are mixed with water and passed

2   through the fluid mover. A combination of the heat

3   addition, the high intensity shearing mechanism, the

4   low pressure region in the vapour-droplet flow and

5   the condensation shock wave both rapidly hydrates

6   the paper fibres, and macerates and disintegrates

7   the paper pieces into smaller sizes. Disintegration

8   down to individual fibres has been achieved in

9   tests. Similarly, the fluid mover could be used in

10   de-inking processes, where the heating and shearing

11   assist in the removal of ink from paper pulp as it

12   passes through the fluid mover.

13

14   The straight through aspect of the invention has the

15   additional benefit of offering very little flow

16   restriction and therefore a negligible pressure

17   drop, when a fluid is moved through it. This is of

18   particular importance in applications where the

19   fluid mover is located in a process pipe work and

20   fluid is pumped through it, such as the case, for

21   example, when the fluid mover of the present

22   invention is turned 'off' by the reduction or

23   stopping of the supply of transport fluid. In

24   addition, the straight through passage and clear

25   bore offers no impedance to cleaning 'pigs' or other

26   similar devices which may be employed to clean the

27   pipe work.

28

29   A detailed description of the energy transfer

30   mechanism, focussing on the momentum transfer

31   between the transport fluid and working fluid by an

32   enhanced shearing mechanism is best described with

1   reference to the accompanying drawings. By way of

2   example, eight embodiments of geometrical features

3   that may be employed to enhance this energy transfer

4   mechanism in accordance with the present invention

5   are described below with reference to the

6   accompanying drawings in which:

7

8   Figure 1 is a cross sectional elevation of a fluid

9   mover according to the present invention;

10   Figure 2 is a magnified view of the shearing

11   mechanism shown in Figure 1;

12   Figure 3 is a cross sectional elevation of a first

13   embodiment;

14   Figure 4 is a cross sectional elevation of a second

15   embodiment;

16   Figure 5 is a cross sectional elevation of a third

17   embodiment;

18   Figure 6 is a cross sectional elevation of a fourth

19   embodiment;

20   Figure 7 is a cross sectional elevation of a fifth

21   embodiment;

22   Figure 8 is a cross sectional elevation of a sixth

23   embodiment;

24   Figure 9 is a cross sectional elevation of a seventh

25   embodiment;

26   Figure 10 is a schematic section through the fluid

27   regime of the fluid mover of the present invention;

28   Figure 11 is a schematic drawing of the fluid mover

29   of the present invention in use;

30   Figure 12 is a schematic drawing showing pressure in

31   the fluid mover of the present invention under three

32   different operating conditions;

1   Figure 13 is a schematic drawing showing a section
2   through the fluid mover of the present invention and
3   the pressure distribution in the fluid mover under
4   two different condensation shock wave positions; and
5   Figures 14a and 14b are partial cross sectional
6   views through an eighth embodiment of the fluid
7   mover of the present invention.
8
9   Like numerals of reference have been used for like
10   parts throughout the specification.
11
12   Referring to Figure 1 there is shown a fluid mover
13   1, comprising a housing 2 defining a passage 3
14   providing an inlet 4 and an outlet 5, the passage 3
15   being of substantially constant circular cross
16   section.
17
18   The housing 2 contains a plenum 8 for the
19   introduction of a transport fluid, the plenum 8
20   being provided with an inlet 10. The distal end of
21   the plenum is tapered on and defines an annular
22   nozzle 16. The nozzle 16 being in flow communication
23   with the plenum 8. The nozzle 16 is so shaped as in
24   use to give supersonic flow.
25
26   In operation the inlet 4 is connected to a source of
27   a process or working fluid. Introduction of the
28   steam into the fluid mover 1 through the inlet 10
29   and plenum 8 causes a jet of steam to issue forth
30   through the nozzle 16. Steam issuing from the
31   nozzle 16 interacts with the working fluid in a
32   section of the passage operating as a mixing chamber

23

1   (3A). In operation the condensation shock wave 17

2   is created in the mixing chamber (3A).

3

4   In operation the steam jet issuing from the nozzle

5   occasions induction of the working fluid through the

6   passage 3 which because of its straight through

7   axial path and lack of any constrictions provides a

8   substantially constant dimension bore which presents

9   no obstacle to the flow. At some point determined

10 by the steam and geometric conditions, and the rate

11 of heat and mass transfer, the steam condenses

12 causing a reduction in pressure. The steam

13 condensation begins shortly before the condensation

14 shock wave and increases exponentially, ultimately

15 forming the condensation shock wave 17 itself.

16

17 The low pressure created shortly before and within

18 the initial phase of the condensation shock wave

19 results in a strong fluid induction through the

20 passage 3. The pressure rises rapidly within and

21 after the condensation shock wave. The condensation

22 shock wave therefore represents a distinct pressure

23 boundary/gradient.

24

25 The parametric characteristics of the steam coupled

26 with the geometric features of the nozzle, upstream

27 wall profile and mixing chamber are selected for

28 optimum energy transfer from the steam to the

29 working fluid. The first energy transfer mechanism

30 is momentum and mass transfer which results in

31 atomisation of the working fluid. This energy

32 transfer mechanism is enhanced through turbulence.

24

1   Figure 1 shows diagrammatically the break-up, or

2   atomisation sequence 18 of the working fluid core.

3

4   Figure 2 shows a magnified and exaggerated schematic

5   of the shearing and atomisation mechanism 18 of the

6   working fluid by the transport fluid. It is

7   believed that this mechanism can be broken down into

8   three distinct regions, each governed by established

9   turbulence mechanisms. The first region 20

10   experiences the first interaction between the

11   transport and working fluid. It is in this region

12   that Kelvin-Helmholtz instabilities in the surface

13   contact layer of the working fluid may start to

14   develop. These instabilities grow due to the shear

15   conditions, pressure gradients and velocity

16   fluctuations, leading to Rayleigh-Taylor ligament

17   break-up 24. Second order eddies within the fluid

18   surface waves may reduce in size to the scale of

19   Kolmogorov eddies 22. It is believed that the

20   formation of these eddies, in association with the

21   Rayleigh-Taylor ligament break-up, result in the

22   formation of small droplets 28 of the working fluid.

23

24   The droplet formation phases may also result in a

25   localised recirculation zone 26 immediately

26   following the ligament break-up region. This

27   recirculation zone may enhance the fluid atomisation

28   further by re-circulating the larger droplets back

29   into the high shear region. This recirculation, a

30   feature of the localised pressure gradient, is

31   controllable via the transport fluid's axial,

32   tangential and radial velocity and pressure

25

1   components. It is believed that this mechanism

2   enhances inter alia the mixing, emulsifying and

3   pumping capabilities of the fluid mover.

4

5   The primary break-up mechanism of the working fluid

6   core may therefore be enhanced by creating initial

7   instabilities in the working fluid flow.

8   Deliberately created instabilities in the transport

9   fluid/working fluid interaction layer encourage

10   fluid surface turbulent dissipation resulting in the

11   working fluid core dispersing into a liquid-ligament

12   region, followed by a ligament-droplet region where

13   the ligaments and droplets are still subject to

14   disintegration due to aerodynamic characteristics.

15

16   Referring now to Figure 3 the fluid mover of Figure

17   1 and 2 is provided with a contoured internal wall

18   in the region 19 immediately upstream of the exit of

19   the steam nozzle 16. The internal wall of the flow

20   passage 3 immediately upstream of the nozzle 16 is

21   provided with a tapering wall 30 to provide a

22   diverging profile leading up to the exit of the

23   steam nozzle 16. The diverging wall geometry

24   provides a deceleration of the localised flow,

25   providing disruption to the boundary layer flow, in

26   addition to an adverse pressure gradient, which in

27   turn leads to the generation and propagation of

28   turbulence in this part of the working fluid flow.

29   As this turbulence is created immediately prior to

30   the interaction between the working fluid and the

31   transport fluid, the instabilities initiated in

32   these regions enhance the Kelvin-Helmholtz

1   instabilities and hence ligament and droplet

2   formation as foreshadowed in the foregoing

3   description occurs more rapidly.

4

5   An alternative embodiment is shown in Figure 4.

6   Again, the fluid mover of Figure 1 and 2 is provided

7   with a contoured internal wall 19 of the flow

8   passage 3 immediately upstream of the nozzle 16.

9   The contoured surface in this embodiment is provided

10   by a diverging wall 30 on the bore surface leading

11   up to the exit of the steam nozzle 16, but the taper

12   is preceded with a step 32. In use, the step

13   results in a sudden increase in the bore diameter

14   prior to the tapered section. The step 'trips' the

15   flow, leading to eddies and turbulent flow in the

16   working fluid within the diverging section,

17   immediately prior to its interaction with the steam

18   issuing from the steam nozzle 16. These eddies

19   enhance the initial wave instabilities which lead to

20   ligament formation and rapid fluid cone dispersion.

21

22   The tapered diverging section 30 could be tapered

23   over a range of angles and may be parallel with the

24   walls of the bore. It is even envisaged that the

25   tapered section 30 may be tapered to provide a

26   converging geometry, with the taper reducing to a

27   diameter at its intersection with the steam nozzle

28   16 which is preferably not less than the bore

29   diameter.

30

31   The embodiment shown in Figure 4 is illustrated with

32   the initial step 32 angled at 90° to the axis of the

1   bore 3. As an alternative to this configuration,
2   the angle of the step 32 may display a shallower or
3   greater angle suitable to provide a 'trip' to the
4   flow. Again, the diverging section 30 could be
5   tapered at different angles and may even be parallel
6   to the walls of the bore 3. Alternatively, the
7   tapered section 30 may be tapered to provide a
8   converging geometry, with the taper reducing to a
9   diameter at its intersection with the steam nozzle
10   16 which is preferably not less than the bore
11   diameter.
12
13   Figures 5 to 8 illustrate examples of alternative
14   contoured profiles. All of these are intended to
15   create turbulence in the working fluid flow
16   immediately prior to the interaction with the
17   transport fluid issuing from the nozzle 16.
18
19   The embodiments illustrated in Figures 5 and 6
20   incorporate single or multiple triangular cross
21   section grooves 34, 36 immediately prior to a
22   tapered or parallel section 30, which is in turn
23   immediately prior to the exit of the steam nozzle
24   16.
25
26   The embodiments illustrated in Figures 7 and 8
27   incorporate single or multiple triangular 38 and/or
28   square 40 cross section grooves a short distance
29   upstream of the exit of the steam nozzle 16. These
30   embodiments are illustrated without a tapering
31   diverging section after the grooves.
32

28

1   Although Figures 1 to 8 illustrate several

2   combinations of grooves and tapering sections, it is

3   envisaged that any combination of these features, or

4   any other groove cross-sectional shape may be

5   employed.

6

7   The tapered section 30 and/or the step 32 and/or the

8   grooves 34, 36, 38, 40 may be continuous or

9   discontinuous in nature around the bore. For

10 example, a series of tapers and/or grooves and/or

11 steps may be arranged around the circumference of

12 the bore in a segmented or 'saw tooth' arrangement.

13

14 The nature of the flow regime in the fluid mover of

15 the present invention is described in more detail

16 below, with reference to Figure 10.

17

18 The transport fluid, usually steam 80, enters

19 through nozzle 16 at supersonic velocity. Wherever

20 the term steam is used, it is to be understood that

21 the term can also be applied to other transport

22 fluids. The working fluid, usually liquid 82, flows

23 at a subsonic velocity into the inlet 4. At the

24 nozzle 16 there is a subsonic liquid core 84 which

25 is bounded by a generally rough or turbulent conical

26 interface with the steam 80 and the region of

27 dispersion 88. As the steam 80 exits the nozzle 16

28 it exhibits local shock and expansion waves 86 and

29 forms a pseudo vena contracta 90. The accelerated

30 region of dispersion 88 (or dissociation) of the

31 liquid core flows at a locally supersonic velocity

32 into the vapour-droplet region 92, in which the

29

1   vapour is steam and the droplets are the working

2   fluid. Condensation takes place in the supersonic

3   condensation zone 94 and the subsonic condensation

4   zone 96. The condensation shock wave 17 is produced

5   when the condensation, which initiates in the

6   locally supersonic low density region 94, reaches an

7   exponential rate. The zone 96 immediately after the

8   condensation shock wave 17 has a considerably higher

9   density and is hence subsonic. The condensation

10   shock wave 17 thus defines the interface between

11   these two densities.

12

13   In the liquid phase 98 beyond the condensation zone

14   96 there are small vapour bubbles. The position of

15   the condensation shock wave is controllable over a

16   distance L by adjustment of one of the plurality of

17   parameters described herein.

18

19   The break-up and dispersion of the primary liquid

20   core produces a droplet vapour region. Any liquid

21   instabilities on the primary liquid cone surface 18

22   are amplified to form 'waves'. These waves are

23   further elongated to form ligaments that undergo

24   Rayleigh-Taylor break-up, resulting in the formation

25   of small droplets 28, separated ligaments 24 and

26   larger droplets.

27

28   The secondary region 24 is thus characterised by the

29   rapid increase in the effective fluid surface area.

30   These droplets 28, of varying size, are then subject

31   to several aerodynamic and thermal effects which

32   ultimately result in their break up to sizes

30

1   characteristic with the turbulence levels in this

2   region. This results in the vapour-droplet region

3   which defines the flow regime within the fluid

4   mover.

5

6   The thickness of the viscous sub layer, comprising

7   the high speed vapour/gas and the locally entrained

8   liquid in droplet or ligament form, increases

9   downstream to ultimately extend across the entire

10   bore. The turbulence within this region arises from

11   shear (velocity gradient) and eddies (large scale to

12   Kolmogorov scale), as the flow is essentially of a

13   vapour-droplet consistency. High levels of shear

14   exist in the gas/liquid interface.

15

16   A large amount of energy is transferred in this

17   secondary region 24 as a result of further particle

18   break-up. Mass transfer takes place as the shear

19   forces and thermal discontinuities result in the

20   droplets becoming ever smaller. The pressure

21   reduces and droplets are evaporated in order to

22   maintain equilibrium in the flow. Heat transfer

23   takes place as equilibrium conditions are reached,

24   ensuring that liquid vapour phase transitions and

25   the inverse transitions all occur within the mixing

26   section of the passage 3. In the secondary region

27   there is a very rapid increase in the void fraction

28   $$\alpha = \frac{A_g}{A_{Tot}}$$

29

30   where α = void fraction

31   A_g = area of gas phase (dispersion cone)

32   A_{Tot} = total area of pump flow

1

2   Thus the rapid increase in specific volume as the

3   liquid droplets/ligaments are further dispersed,

4   will obviously result in a larger void fraction.

5   Subsequently as the flow conditions begin to

6   approach a state of equilibrium, and due to the

7   geometry within the mixing chamber, the vapour flow

8   is encouraged to follow a condensation profile

9   towards an aerodynamic and condensation shock wave,

10 which is a region of non-equilibrium and entropy

11 production.

12

13 The condensation shock wave arises from the rapid

14 change from a two-phase fluid mixture to a

15 substantially single phase fluid with complete

16 condensation of the vapour phase. Since there is no

17 unique sonic speed in vapour droplet mixtures, non-

18 equilibrium and equilibrium exchanges of momentum,

19 mass and energy can occur. In order to achieve a

20 normal condensation shock wave, the velocity of the

21 vapour mixture within the mixing chamber has to be

22 maintained above a certain value defined as the

23 equilibrium sonic speed. For conditions where the

24 vapour velocity is greater than the frozen sonic

25 speed, or where the velocity of the vapour mixture

26 is between the equilibrium and frozen sonic speed,

27 this results in a dispersed or partially dispersed

28 condensation shock wave. These two asymptotic sonic

29 speeds are:

30

32

1   a_e = equilibrium shock speed. This is the speed at
2   which every fluid is in its correct equilibrium
3   condition, i.e. vapour is vapour, liquid is liquid
4
5   a_f = frozen shock speed. This occurs primarily due
6   to a 'lag' effect, so that some fluids are not in
7   their correct phase, for example the local
8   temperature and pressure dictate that a vapour
9   should be turning to liquid, but the phase change
10 has not happened.
11
12 a_f and a_e are defined as:
13
14 $$a_f = \sqrt{\gamma \cdot R_v \cdot T_s}$$
15

16 $$a_e = \sqrt{\frac{\chi \cdot \gamma \cdot R_v \cdot T_s}{\gamma\left[1 - \frac{R_v \cdot T_s}{h_{fg}}\left(2 - \frac{c \cdot T_s}{h_{fg}}\right)\right]}}$$

17
18 where
19

20 $$c = Cp_v + \frac{\left(\frac{1-\varepsilon}{\varepsilon}\right)}{Cp_f}$$

21 γ = Ratio of specific heats (the vapour and the
22 fluid)
23 R_v = Gas constant for vapour phase (steam)
24 T_s = Saturation temperature of mixture (vapour and
25 fluid)
26 Cp = Specific heat
27 H_{fs} = Latent heat of vapourisation
28 χ = Initial vapour quality
29 ε = Vapour fraction (gas/liquid)
30

1   Subscript v, represents vapour (steam)

2   Subscript f, represents fluid (e.g. liquid)

3

4   Frozen flow arises when the interface transport of

5   mass, momentum and energy between the vapour phase

6   and liquid droplets is frozen completely, i.e. the

7   liquid droplets do not take part in the fluid

8   mechanical processes.

9

10   Equilibrium flow arises when the velocity and

11   temperature of the vapour and liquid are in

12   equilibrium, and the partial pressure due to the

13   vapour is equal to the saturation pressure

14   corresponding to the temperature of the flow.

15

16   The secondary flow regime can better be understood

17   by further subdivision into three sub-regions.

18

19   The first sub-region of the secondary flow regime is

20   the droplet break-up sub-region. Just as in the

21   primary zone, where the liquid core is stripped to

22   form the droplet-vapour zone, with the stripping of

23   the ligaments and droplets on the surface, so in the

24   secondary region there is further break-up or

25   dispersion of these separated ligaments, and also

26   the break-up of droplets whose characteristics are

27   unstable in the turbulent flow regime. The dominant

28   mechanism responsible for the break-up in the

29   secondary region is the acceleration of droplets or

30   momentum transfer due to the slip velocity between

31   vapour and liquid. The injection velocity of the

32   vapour in the present invention is important to this

1   functional aspect of the flow regime. If required,

2   multiple nozzles staggered downstream may be used to

3   encourage this aspect. Other parameters such as

4   nozzle angle and mixing chamber geometry can be

5   selected to establish favourable flow conditions.

6

7   Typical break-up mechanisms in this region are

8   dependant on the local velocity slip conditions and

9   the respective working fluid properties. These are

10 gathered into a dimensionless number referred to as

11 the aerodynamic Weber number defined as:

12

13 $$We = \frac{\rho_v \cdot \left(U_f - U_v\right)^2 \cdot D_f}{\sigma_f}$$

14

15 where

16 ρ_v = Density of vapour

17 U = Velocity

18 D_f = Hydraulic diameter of fluid

19 σ_f = Surface tension of fluid

20

21 Typical break-up mechanisms found in the fluid mover

22 of the present invention are vibrational break-up,

23 which can be found with ligaments and droplets whose

24 characteristic length is greater than the stable

25 length; catastrophic break-up, which is especially

26 dominant in the liquid-vapour shear layer where We

27 ≥350; wave crest stripping, which occurs where

28 droplets, due to their size, experience large

29 aerodynamic forces causing ellipsoidal shapes,

30 typically where We ≥300; and short stripping, which

31 is the dominant break-up mechanism where daughter

35

1   and sattelite droplets have been formed following

2   the ligament stripping and dispersion, typically

3   where We≥100.

4

5   The turbulent motion of the surrounding gas,

6   especially where the Reynold numbers are large (Re >

7   10^4), as is usually the case in the present

8   invention, results in large amounts in local energy

9   dissipation and accompanying droplet break-up. The

10 fluctuating dynamic pressures resulting from these

11 turbulent fluctuations are dominant in droplet

12 break-up but very importantly it is this energy that

13 ensures extremely effective dispersion and mixing of

14 the fluids in the flow.

15

16 Turbulent pressure fluctuations result in shear

17 forces capable of rupturing fibres or filaments and

18 dissipating powder lumps or similar solid or semi-

19 solid matter. In the primary region energy, mass

20 and momentum transfer takes place through a more

21 distinct boundary, associated with the liquid cone

22 dispersion. In the secondary break-up region this

23 transfer is directly related to the turbulence

24 intensity, closely associated with the turbulent

25 dissipation region in the flow.

26

27 The thermal boundary layer, although similar in

28 characteristic to the turbulent dissipation

29 sublayer, represents the effective boundary where

30 evaporation/condensation and energy transfer occur

31 in either an equilibrium state or 'frozen' state.

32

36

1　　Interfacial transport, which begins within the
2　　primary cone dissipation, continues into the
3　　secondary vapour-droplet region and is characterised
4　　by distinct mechanisms enhanced within the fluid
5　　mover of the invention through vapour introduction
6　　conditions, dependent on pressure and velocity, the
7　　physical geometry of the steam nozzles and the
8　　mixing chamber geometry. This results in a
9　　continuous surface renewal process, which together
10　　with the turbulence results in a series of renewed
11　　eddies of various scales. These eddies create
12　　bursts arising from the interface of the liquid
13　　vapour and the waves formed on ligaments and
14　　droplets which are undergoing further break-up.
15　　These bursts have a period which is a function of
16　　the interfacial shear velocity. These bursts
17　　greatly encourage mixing, heat transport and
18　　emulsification (droplet size reduction).
19
20　　The second sub-region of the secondary flow regime
21　　is the subcooled vapour-droplet region. As the
22　　vapour mixture flows through the fluid mover of the
23　　invention its velocity profile is adjusted through
24　　fluidic interaction as well as the static pressure
25　　gradient which gradually rises due to general
26　　deceleration of the flow. This controlled diffusion
27　　of the supersonic flow, balance of natural fluidic
28　　and thermodynamic interactions coupled with discrete
29　　geometry results in a vapour-droplet state where
30　　sub-cooled droplets exist within a vapour dominant
31　　phase. The sub-cooled state of this frozen mixture
32　　increases until droplet nucleation, and hence

1   condensation, begins to occur very rapidly. The

2   point of maximum sub-cooling (Wilson point)

3   determines the point at which the nucleation rate,

4   which is closely dependent on sub-cooling because of

5   the available surface area for condensation, begins

6   to occur very rapidly, and reaches near exponential

7   rates. The vapour-droplet region within the fluid

8   mover of the invention thus is able to attain near

9   thermodynamic equilibrium within a very short zone.

10

11   The fluid mover of the invention makes special use

12   of geometric conditions created through both

13   geometry and pseudo geometric conditions to ensure

14   the flow conditions upstream of the critical

15   subcooled state deviate from the thermodynamic

16   equilibrium. This ensures maintenance of the

17   desired vapour-droplet region with its desirable

18   droplet break-up, particle dispersion and heat

19   transfer effects.

20

21   The rapid acceleration of the fluid from the primary

22   fluid cone into the vapour region results in an

23   expansion wave, which similarly represents a

24   thermodynamic discontinuity and allows the vapour

25   droplet region to deviate markedly from equilibrium

26   and enter a 'frozen' flow condition.

27

28   Figure 9 shows an embodiment of the fluid mover of

29   the invention in which the geometry of the passage 3

30   has a mixing chamber 3A with a divergent region 50,

31   a constant diameter region 52 and a re-convergence

32   profile region 54. The constant through bore is

1 maintained, but the embodiment of Fig 9 promotes

2 this expansion and non-equilibrium. This offers

3 excellent particle dispersion, and good flow,

4 pressure head and suction conditions.

5

6 The third sub-region of the secondary flow regime is

7 the condensation shock region. As a result of the

8 sub-cooled vapour-droplet flow regime within the

9 fluid mover, the point at which exponential

10 condensation begins to occur defines the

11 condensation shock wave boundary. The mixture

12 conditions upstream of the condensation shock wave

13 determine the nature of the pressure and temperature

14 recovery experienced within the fluid mover.

15

16 The phase change across the condensation shock wave

17 obviously results in heat removal from the vapour

18 phase, although there will be an entropy increase

19 across the condensation shock wave. The ideal

20 operating conditions in the fluid mover of the

21 invention coincide with the formation of a normal

22 condensation shock wave, referred to as being

23 discrete, due to its relatively rapid and hence

24 negligible size measured along the X-axis.

25

26 The nature of the fluid flow in the fluid mover of

27 the present invention may better be understood by

28 reference to Figure 12, which shows the distribution

29 of pressure p in the fluid mover over length x along

30 the axis. Reference is made to the two shock

31 speeds, a_e and a_f, defined earlier.

32

1　Fig. 12a shows condition A and represents the

2　situation where $U_{mixture} > a_e$, where $U_{mixture}$ is the

3　velocity of the vapour/droplet mixture.

4

5　This results in a normal condensation shock wave,

6　with a fairly rapid rise in pressure across the

7　condensation shock wave. The resulting exit

8　pressure is higher than the local pressure at the

9　steam inlet into the bore of the fluid mover.

10

11　Fig. 12b shows condition B and represents the

12　situation where $a_f > U_{mixture} > a_e$. In this case the

13　mixture velocity is higher than the equilibrium

14　shock speed but less than the frozen shock speed.

15　In this condition the condensation shock wave is

16　fully dispersed resulting in a much more gradual

17　pressure rise across the condensation shock wave.

18

19　Fig. 12c shows condition C and represents the

20　situation where $U_{mixture} > a_f$. In this condition an

21　'unstable' condition arises, with the steam not

22　fully condensing. This is referred to as a

23　partially dispersed condensation shock wave. This

24　results in the start of the formation of a

25　condensation shock wave (with a reasonably steep

26　pressure gradient), the condensation shock wave

27　formation 'stalling', and then restarting again.

28　However, it has been found that the final resulting

29　exit pressure is often higher than for either

30　Condition A or Condition B.

31

1   There are several mechanisms for determining the
2   state of the flow regime in the fluid mover, and
3   using this information in a control system to
4   provide the flow regime that best meets the demands
5   of the application. For example one can measure the
6   temperature at a particular point along the length
7   of the mixing chamber, to determine the existence of
8   a vapour-droplet region. Such a method is non-
9   intrusive since the mixer wall can be of thin
10   section allowing a rapid response to the change in
11   conditions. Multiple temperature probes spaced
12   downstream of one another can be used to monitor the
13   position of the condensation shock wave, as well as
14   to determine the state of the condensation shock
15   wave profile.
16
17   As a further example the use of pressure sensors
18   allows the condensation shock wave position to be
19   determined.
20
21   With reference to Figures 13 and 14 there is shown a
22   method of using a series of pressure sensors to
23   detect the position of the condensation shock wave
24   in the mixing chamber. When the condensation shock
25   wave 17 is in the position 17A indicated by Case 1,
26   i.e. in the convergent profile portion 3C of the
27   passage 3, the pressure profile is shown with the
28   reference numeral 101. When the condensation shock
29   wave 17 is in the position 17B indicated by Case 2,
30   i.e. in the uniform profile portion 3B of the
31   passage 3, the pressure profile is shown with the
32   reference numeral 102. Pressure sensors P1, P2 and

1   P3 in the passage 3 can be used to measure the

2   pressure at three points 103, 104, 105 along the

3   passage. The pressure measurements at these points

4   can be used to determine the position of the

5   condensation shock wave 17. Depending on the flow

6   profile required, one or more parameters, as

7   described hereinbefore, can be changed to alter the

8   flow profile and the position of the condensation

9   shock wave 17.

10

11   Figure 14a shows a typical pressure sensor, although

12   it is to be understood that this is not limiting,

13   and any suitable pressure sensor or measuring device

14   may be used. This method of measuring pressures in

15   the mixing chamber is especially suited for

16   condensation shock wave detection, since the

17   measurement technique only needs to measure a change

18   in pressure rather than being calibrated to measure

19   accurate values.

20

21   The mixing chamber 3A is sleeved with a thin walled

22   inner sleeve 107 of suitable material, such as

23   stainless steel. A thin layer of oil 108 fills the

24   gap between the sleeve 107 and the inner wall 106 of

25   the mixing chamber 3A. The pressure sensor P1 is

26   located through the wall 106 of the mixing chamber

27   and is in contact with the oil 108. When the

28   pressure inside the mixing chamber 3A changes, the

29   sleeve 107 expands or contracts a small amount,

30   thereby increasing or decreasing the pressure in the

31   oil 108, which is then detected by the pressure

32   sensor P1.

1

2   In the embodiment of Figure 14b the sleeve 107 is

3   segmented so that the oil is separated by walls 109

4   fixed to the sleeve. This results in separate

5   individual chambers of oil 108A, 108B, each with

6   their own pressure sensor P1, P2. A number of

7   separate chambers and pressure sensors may be

8   arranged along the wall 106 of the mixing chamber

9   3A.

10

11   The advantage of this instrumentation method is that

12   the sleeve 107 provides a clean inner bore, free of

13   any crevices or other features in which working

14   fluid or other transported material can become

15   trapped. This is of particular relevance for use in

16   the food industry. In addition, the pressure sensor

17   P1 is free from contamination, suffers no wear or

18   abrasion, and does not become blocked.

19

20   A further possible way of monitoring the

21   condensation shock wave is by the use of acoustic

22   signatures. Due to the density variation in the

23   mixer, even during powder addition, it is possible

24   to determine the 'state' of flow which is an

25   indication of vapour flow, and hence the condition

26   of having a condensation shock wave. The mechanisms

27   for determining the state of the flow regime in the

28   fluid mover may of course be combined.

29

30   Figure 11 shows an embodiment of the fluid mover 1

31   with various control means for controlling the

32   parameters of the flow. The inlet 4 is in fluid

43

1   communication with a working fluid valve 66 which

2   can be used to control the flow rate and/or inlet

3   pressure of the working fluid. A heating means or

4   cooling means (not shown) may be provided upstream

5   or downstream of the valve 66 to control the inlet

6   temperature of the working fluid. The outlet 5 is

7   in fluid communication with an optional working

8   fluid outlet valve 68 which can be used to control

9   the outlet pressure of the working fluid.

10

11   A transport fluid source 62, such as a steam

12   generator, is controllable to provide transport

13   fluid through the transport passage 64 to the plenum

14   8. The source 62 can be used to control the inlet

15   temperature and/or the flow rate and/or the inlet

16   pressure of the transport fluid.

17

18   The nozzle or nozzles 16 may be mounted for

19   adjustable movement such that a nozzle angle control

20   means (not shown) can be used to control the angle

21   of entry of the transport fluid to the passage.

22

23   The internal dimensions of the passage downstream of

24   the nozzle 16 can be adjusted by means of moveable

25   wall sections 60, which can alter the mixing chamber

26   wall profile between convergent, parallel and

27   divergent at a plurality of sections along the

28   mixing chamber 3A.

29

30   An additive fluid source 70 may be provided to add

31   one or more fluids to the working fluid. An

32   additive fluid valve 72 can be used to control the

44

1   flow rate of the additive fluid, including to switch

2   the flow on or off as appropriate. Separate heating

3   means may be provided for the additive fluid, which

4   may be a heated liquid, a gas such as steam or a

5   mixture. The additive may be a powder, and may be

6   introduced through a valve means from a secondary

7   hopper.

8

9   Control means such as a microprocessor may be

10 provided to control some or all of the parameters

11 described above as appropriate. The control means

12 can be linked to the condensation monitoring

13 devices, such as the pressure sensors P1, P2, P3

14 which monitor the condensation shock wave, or any

15 other sensor means eg temperature or acoustic

16 sensors.

17

18 The versatility of the fluid mover of the present

19 invention allows it to be applied in many different

20 applications over a wide range of operating

21 conditions. Two of these applications will now be

22 described, by way of example, to illustrate the

23 industrial applicability of the fluid mover of the

24 present invention.

25

26 The first of the applications is a method of

27 activating starch. The nature of the energy

28 transfer between the transport fluid and the working

29 fluid affords significant advantages for use in

30 starch activation. Due to the intimate mixing

31 between the hot transport fluid and the working

32 fluid, very high heat transfer rates between the

45

1   fluids are achieved resulting in rapid heating of

2   the working fluid. In addition, the high energy

3   intensity within the unit, especially the high

4   momentum transfer rates between the steam and

5   working fluid result in high shear forces on the

6   working fluid. It is therefore this combination of

7   heat and shear that result in enhanced starch

8   activation.

9

10   The fluid mover may be incorporated in either a

11   batch or a single pass fluid processing

12   configuration. One or more fluid movers may be used,

13   possibly mounted in series in a single pipeline

14   configuration. A single fluid mover may pump, heat,

15   mix, and activate the starch, or a separate pump may

16   be used to pass the working fluid through the fluid

17   mover. Alternatively, two or more fluid movers may

18   be used in series, each fluid mover may be

19   configured and optimized to carry out different

20   roles. For example, one fluid mover may be

21   configured to pump and mix (and do some initial

22   heating) and a second fluid mover mounted in series

23   down stream of the first, optimized to heat.

24

25   The energy intensity within the fluid mover is

26   controllable. By controlling the flow rates of the

27   steam and/or the working fluid, the intensity can be

28   reduced to allow slow heating of the working fluid,

29   and provide a much lower shear intensity. This could

30   be used, for example, to provide gentle heating of

31   the working fluid to maintain a batch of working

1   fluid at a constant temperature without causing any

2   shear thinning.

3

4   This method may also be employed for entraining,

5   mixing in, dispersing and dissolving other hard-to-

6   wet powders commonly employed in the food industry,

7   such as pectins. Pectins are typically used to

8   thicken foods or form gells, and are activated by

9   heat. Some pectins form thermoreversible gels in the

10   presence of calcium ions whereas others rapidly form

11   thermally irreversible gels in the presence of

12   sufficient sugars. The intense mixing, agitation,

13   shear and heating afforded by the Fluid Mover

14   enhances these gelling processes.

15

16   By way of example only, a fluid mover has been used

17   to pump, mix, homogenise, heat (cook) and activate

18   the starch in the manufacture of a 65kg batch of

19   tomato based sauce. Conventional processing required

20   the sauce to be heated to 85°C to activate the

21   starch. It was found, using the fluid mover to mix,

22   heat and process the sauce, that the starch was

23   activated at the much lower batch temperature of

24   70°C. Combining this saving in heating requirement

25   with the highly efficient mixing and heating

26   afforded by the fluid mover, the overall process

27   time was reduced by up to 95% over the conventional

28   tank heating and stirring method.

29

30   It has also been found that the Fluid Mover

31   activates a higher percentage of the starch present

32   in the mix than conventional methods. It is not

1 uncommon with food mixes containing highly modified

2 starches for a large percentage (greater than 50%)

3 of the starch to sometimes remain inactivated.

4 Activating a higher percentage of the starch

5 provides an obvious commercial advantage of reducing

6 the amount of starch that has to be added to a mix

7 to achieve a target viscosity. A similar effect has

8 been observed with the (relatively) expensive

9 pectin. Reducing the amount of pectin that has to be

10 added to a mix provides a significant cost saving to

11 the process.

12

13 This method may alternatively be employed in the

14 brewing industry. The brewing process requires the

15 rapid mixing, heating and hydration of ground malt,

16 known as grist, and activation of the starch. It has

17 been found that this can be achieved using the

18 method described in this invention, with the

19 additional advantages of maintaining the integrity

20 of both the enzymes and the husks of the grist.

21 Maintaining integrity of the enzymes in the mix is

22 important as they are required to convert the starch

23 to sugar in a later process, and similarly, the

24 husks are required to be of a particular size to

25 form an effective filter cake in a later Lauter

26 filtration process.

27

28 The second application offered by way of example is

29 a method of enhancing bioethanol (biofuel)

30 production using the fluid mover of the present

31 invention. The nature of the energy transfer

32 between the steam and the working fluid affords

48

1   significant advantages for use in bioethanol

2   production. Due to the intimate mixing between the

3   hot transport fluid (steam) and the working fluid,

4   very high heat transfer rates between the fluids are

5   achieved resulting in rapid heating of the working

6   fluid. In addition, the high energy intensity within

7   the unit, especially the high momentum transfer

8   rates between the steam and working fluid result in

9   high shear forces on the working fluid.

10

11 Two or more fluid movers may be used in series, each

12 fluid mover may be configured and optimized to carry

13 out different roles. For example, one fluid mover

14 may be configured to pump and mix (and do some

15 initial heating) and a second fluid mover mounted in

16 series down stream of the first, optimized to heat

17 and macerate.

18

19 Utilising the method described in this invention,

20 the process of mixing, heating, hydrating and

21 macerating the carbohydrate polymers in the biomass

22 can be achieved more rapidly and efficiently than

23 conventional methods. Utilising the high shear and

24 the presence of shockwave allows the active chemical

25 or biological components to be intimately mixed with

26 the carbohydrate polymers more efficiently,

27 enhancing the contact through pulping of the plant

28 matter as it begins to breakdown. Although the

29 method described in this invention utilizes high

30 temperature and high shear, it is still suitable for

31 use in an Enzymatic Hydrolysis process without

32 damage to the enzymes.

The shape of the fluid mover of the present
invention may be of any convenient form suitable for
the particular application. Thus the fluid mover of
the present invention may be circular, curvilinear
or rectilinear, to facilitate matching of the fluid
mover to the specific application or size scaling.
The enhancements of the present invention may be
applied to the fluid mover in any of these forms.

The fluid mover of the present invention thus has
wide applicability in industries of diverse
character ranging from the food industry at one end
of the chain to waste disposal at the other end.

The present invention when applied to the fluid
mover of the aforementioned patent affords
particularly enhanced emulsification and
homogenisation capability. Emulsification is also
possible with the deployment of the fluid mover of
the present invention on a once-through basis thus
obviating the need for multi-stage processing. In
this context also the mixing of different liquids
and/or solids is enhanced by virtue of the improved
shearing mechanism which affects the necessary
intimacy between the components being brought
together as exemplified heretofore.

The localised turbulence within the working fluid
dispersion region provides rapid mixing, dispersion
and homogenisation of a range of different fluids
and materials, for example powders and oils.

1

2　The heating of fluids and/or solids can be effected

3　by the use of the present invention with the fluid

4　mover by virtue of the use of steam as the transport

5　fluid and of course in this respect the invention

6　has multi-capability in terms of being able to pump,

7　heat, mix and disintegrate etc.

8

9　The fluid mover of the present invention may be

10　utilised, for example, in the essence extraction

11　process such as decaffeination. In this example the

12　fluid mover may be utilised to pump, heat, entrain,

13　hydrate and intimately mix a wide range of aromatic

14　materials with a liquid, usually water.

15

16　The vapour-droplet flow region of the present

17　invention provides a particular advantage for the

18　hydration of powders. Even extremely hard-to-wet

19　hydrophilic powders, for example Guar gum, may be

20　entrained and dispersed into a fluid medium within

21　this vapour-droplet region.

22

23　As has been disclosed above, the fluid mover of the

24　present invention possesses a number of advantages

25　in its operational mode and in the various

26　applications to which it is relevant. For example

27　the 'straight-through' nature of the fluid mover

28　having a substantially constant cross section, with

29　the bore diameter never reducing to less than the

30　bore inlet, means that not only will fluids

31　containing solids be easily handled but also any

32　rogue material will be swept through the mover

51

1   without impedance. The fluid mover of the present

2   invention is tolerant of a wide range of particulate

3   sizes and is thus not limited as are conventional

4   ejectors by the restrictive nature of their physical

5   convergent sections.

6

7   Modifications and improvements may be incorporated

8   without departing from the scope of the invention as

9   defined in the appended claims.

52

CLAIMS:

1   1.   A fluid mover comprising:

2   a hollow body provided with a straight-through

3   passage of substantially constant cross section with

4   an inlet at one end of the passage and an outlet at

5   the other end of the passage for the entry and

6   discharge respectively of a working fluid;

7   a nozzle substantially circumscribing and

8   opening into said passage intermediate the inlet and

9   outlet ends thereof;

10   an inlet communicating with the nozzle for the

11 introduction of a transport fluid; and

12   a mixing chamber being formed within the

13 passage downstream of the nozzle;

14   wherein the nozzle internal geometry and the

15 bore profile of the passage immediately upstream of

16 the nozzle exit are so disposed and configured to

17 optimise the energy transfer between the transport

18 fluid and working fluid that in use through the

19 introduction of transport fluid the working fluid or

20 fluids are atomised to form a dispersed

21 vapour/droplet flow regime with locally supersonic

22 flow conditions within a pseudo-vena contracta,

23 resulting in the creation of a supersonic

24 condensation shock wave within the downstream mixing

25 chamber by the condensation of the transport fluid.

26

27 2.   The fluid mover according to Claim 1, wherein

28 the passage is a substantially circular passage and

29 the nozzle is an annular nozzle substantially

30 circumscribing the passage.

53

3. The fluid mover according to either preceding claim, wherein the nozzle is of a convergent-divergent geometry internally thereof.

4. The fluid mover according to Claim 4, wherein the nozzle is configured to give the supersonic flow of transport fluid within the passage.

5. The fluid mover according to any preceding claim, wherein the bore profile of the passage immediately upstream of the nozzle is configured to encourage working fluid atomisation.

6. The fluid mover according to any preceding claim and comprising:
   a plurality of nozzles substantially circumscribing and opening into said passage intermediate the inlet and outlet ends thereof;
   a plurality of inlets, each inlet communicating with a respective nozzle for the introduction of a transport fluid; and
   a plurality of mixing chambers, each mixing chamber being formed within the passage downstream of a respective nozzle.

7. A method of moving a working fluid, the method comprising the steps of:
   presenting a fluid mover to the working fluid, the mover having a straight-through passage of substantially constant cross section;

1   applying a substantially circumscribing stream

2   of a transport fluid to the passage through an

3   annular nozzle;

4   atomising the working fluid to form a dispersed

5   vapour and droplet flow regime with locally

6   supersonic flow conditions;

7   generating a supersonic condensation shock wave

8   within the passage downstream of the nozzle by

9   condensation of the transport fluid;

10   inducing flow of the working fluid through the

11   passage from an inlet to an outlet thereof; and

12   modulating the condensation shock wave to vary

13   the working fluid discharge from the outlet.

14

15   8.   The method of Claim 7, wherein the modulating

16   step includes modulating the intensity of the

17   condensation shock wave.

18

19   9.   The method of either Claim 7 or Claim 8,

20   wherein the modulating step includes modulating the

21   position of the condensation shock wave.

22

23   10.   The method of any of Claims 7 to 9, further

24   comprising the step of introducing an instability in

25   working fluid flow immediately upstream of the

26   nozzle.

27

28   11.   A method of processing a working fluid, the

29   method comprising the steps of:

30   presenting a fluid mover to the working fluid,

31   the fluid mover having a straight-through passage of

32   substantially constant cross section;

1   applying a substantially circumscribing stream

2   of a transport fluid to the passage through an

3   annular nozzle;

4   atomising the working fluid to form a dispersed

5   vapour and droplet flow regime with locally

6   supersonic flow conditions;

7   generating a supersonic condensation shock wave

8   within the passage downstream of the nozzle by

9   condensation of the transport fluid, the position of

10   the condensation shock wave remaining substantially

11   constant under equilibrium flow;

12   inducing flow of the working fluid through the

13   passage from an inlet to an outlet thereof; and

14   changing the position of the condensation shock

15   wave to vary the working fluid discharge from the

16   outlet.

17

18   12. The method according to any of Claims 7 to 11,

19   wherein the transport fluid is steam.

Fig. 1

2 / 9

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

16

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Fig. 7

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2

3

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Fig. 8

6 / 9

Fig. 9

Fig. 10

Fig. 11
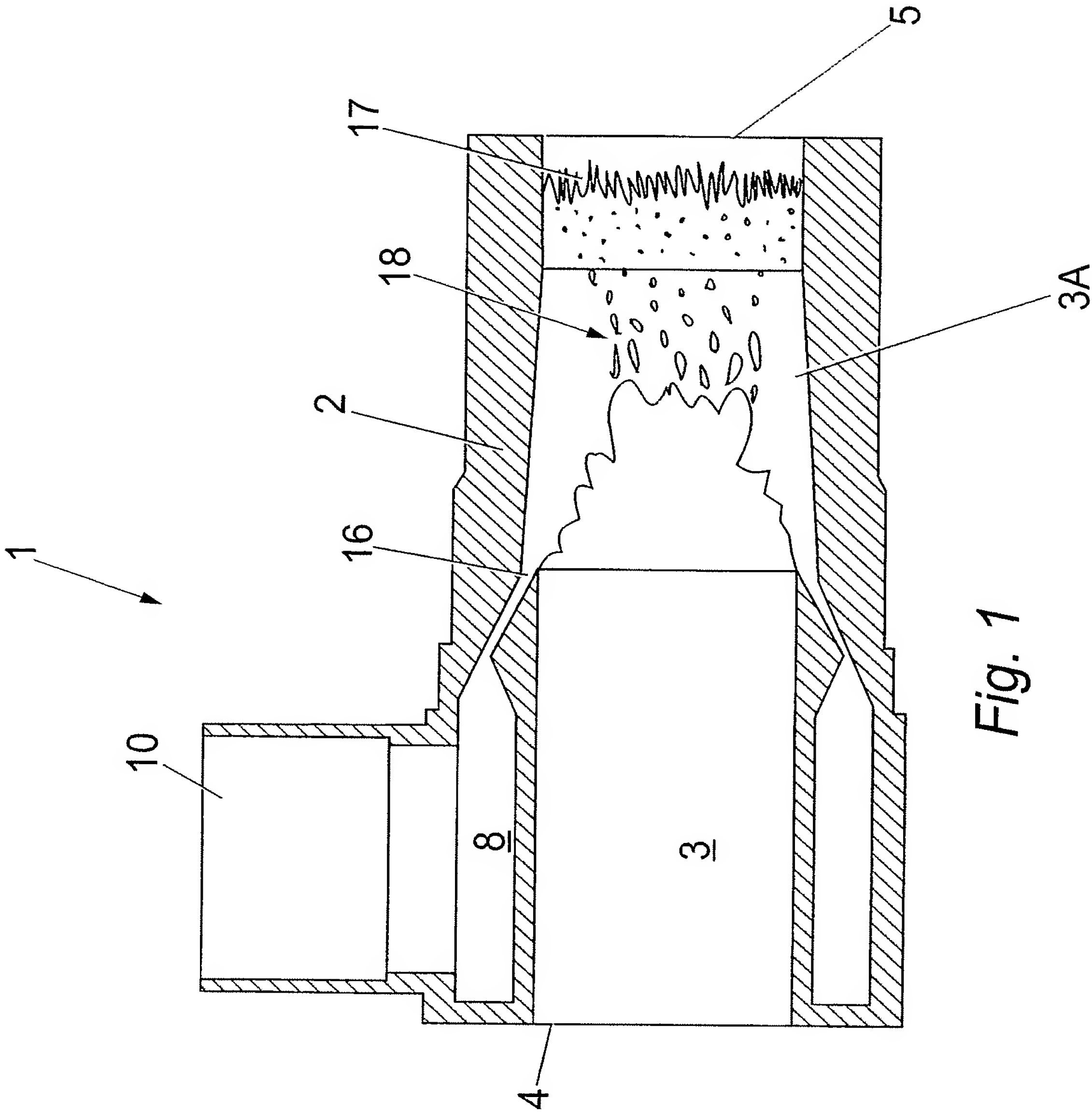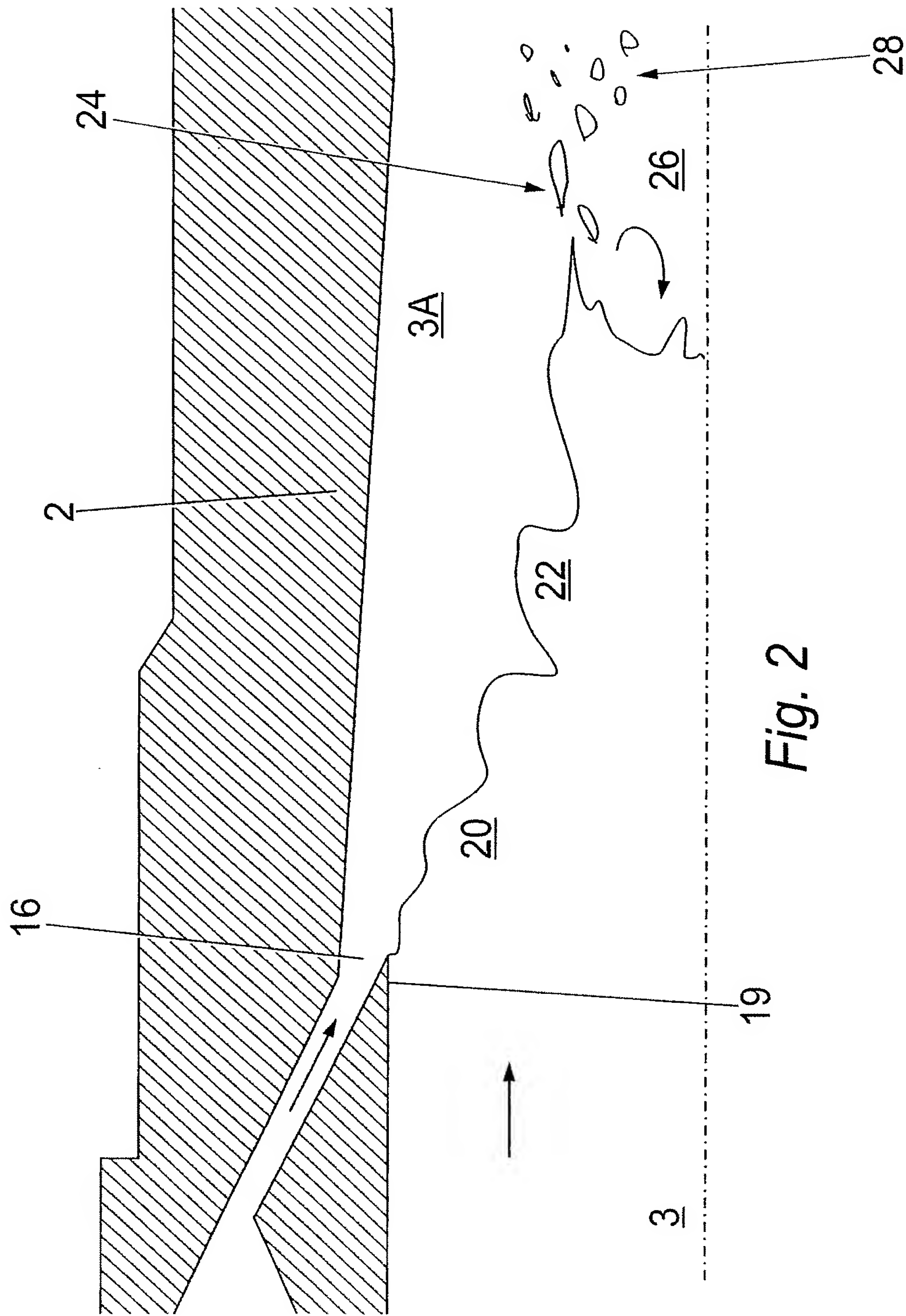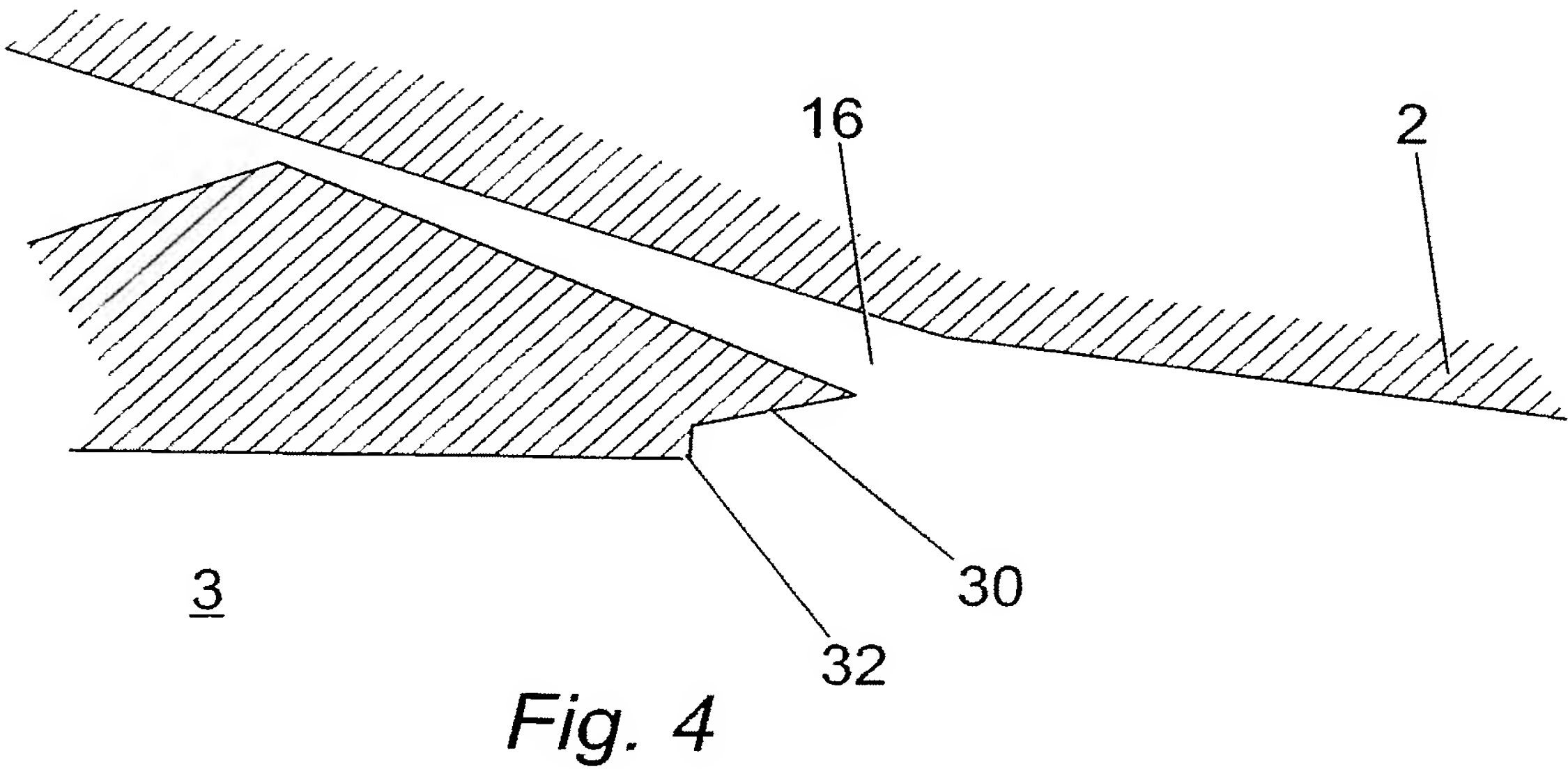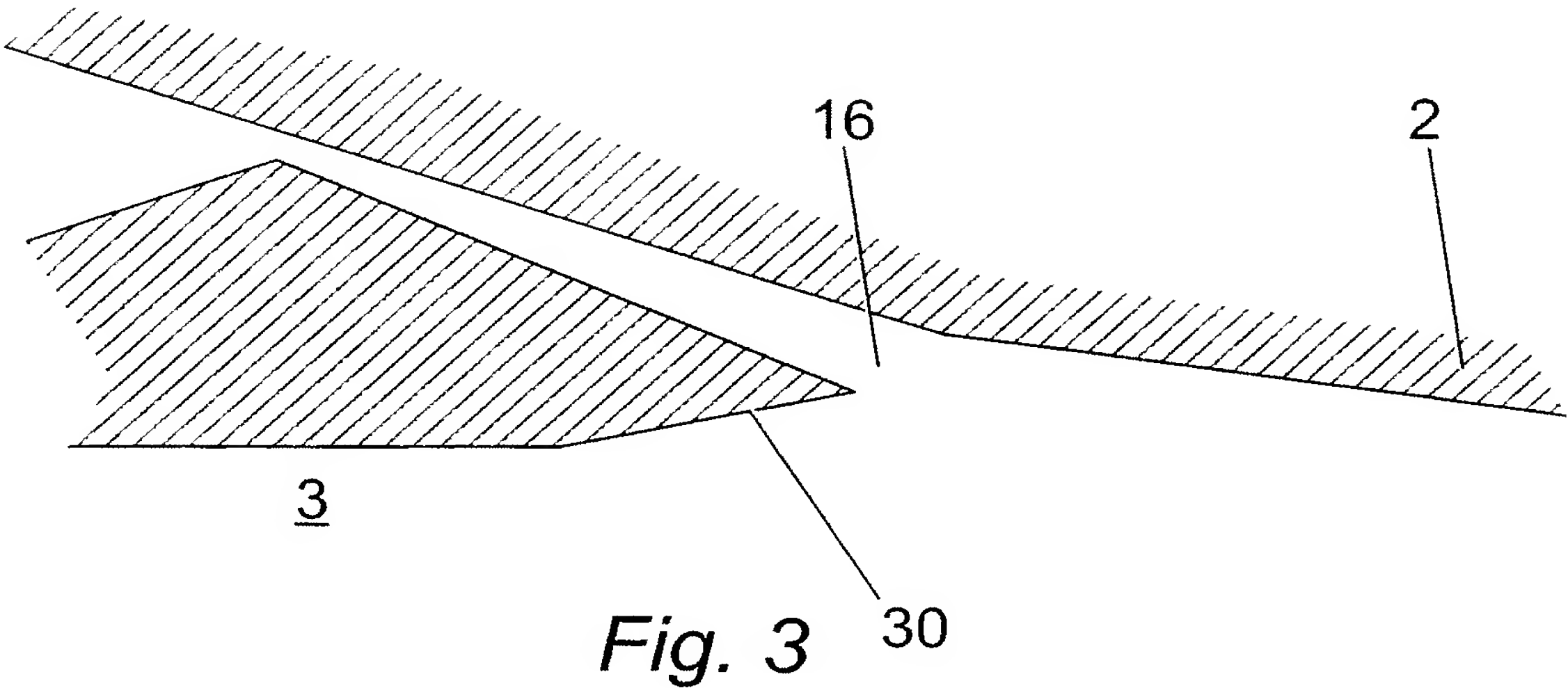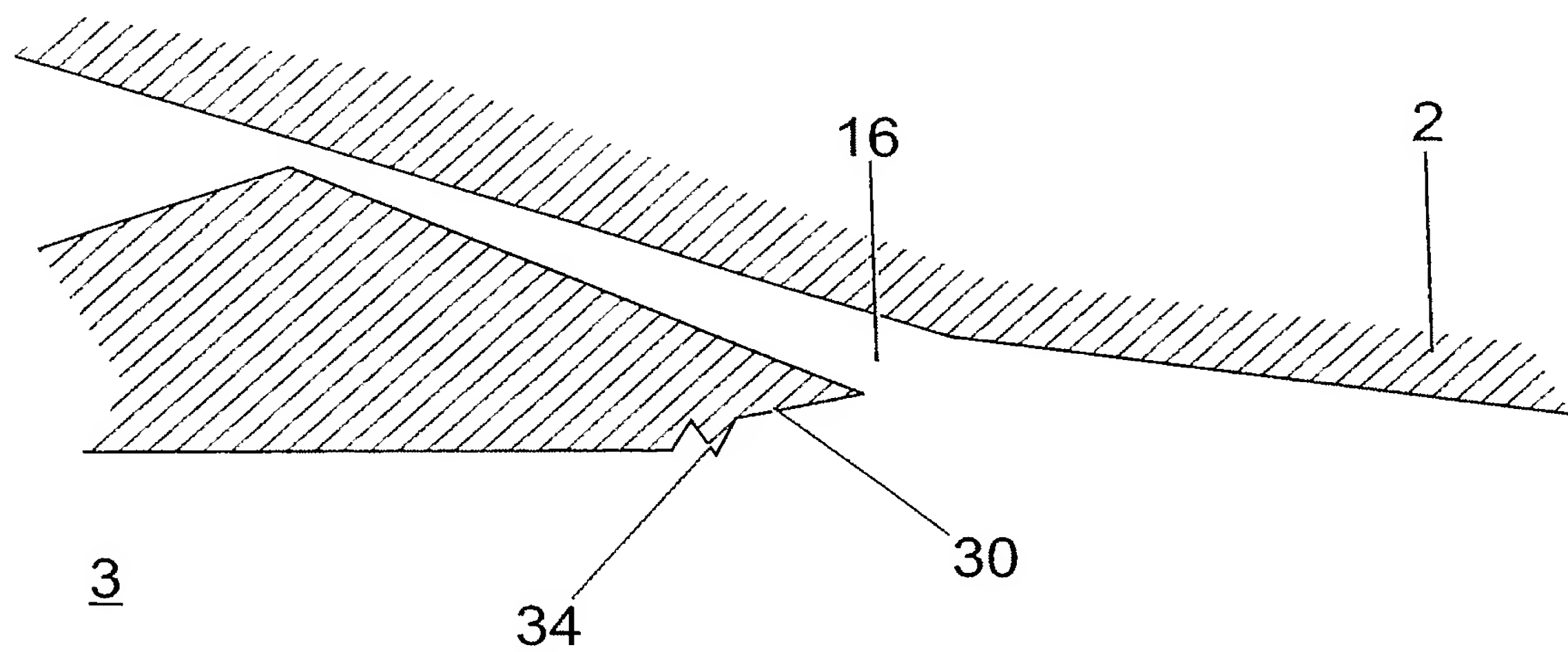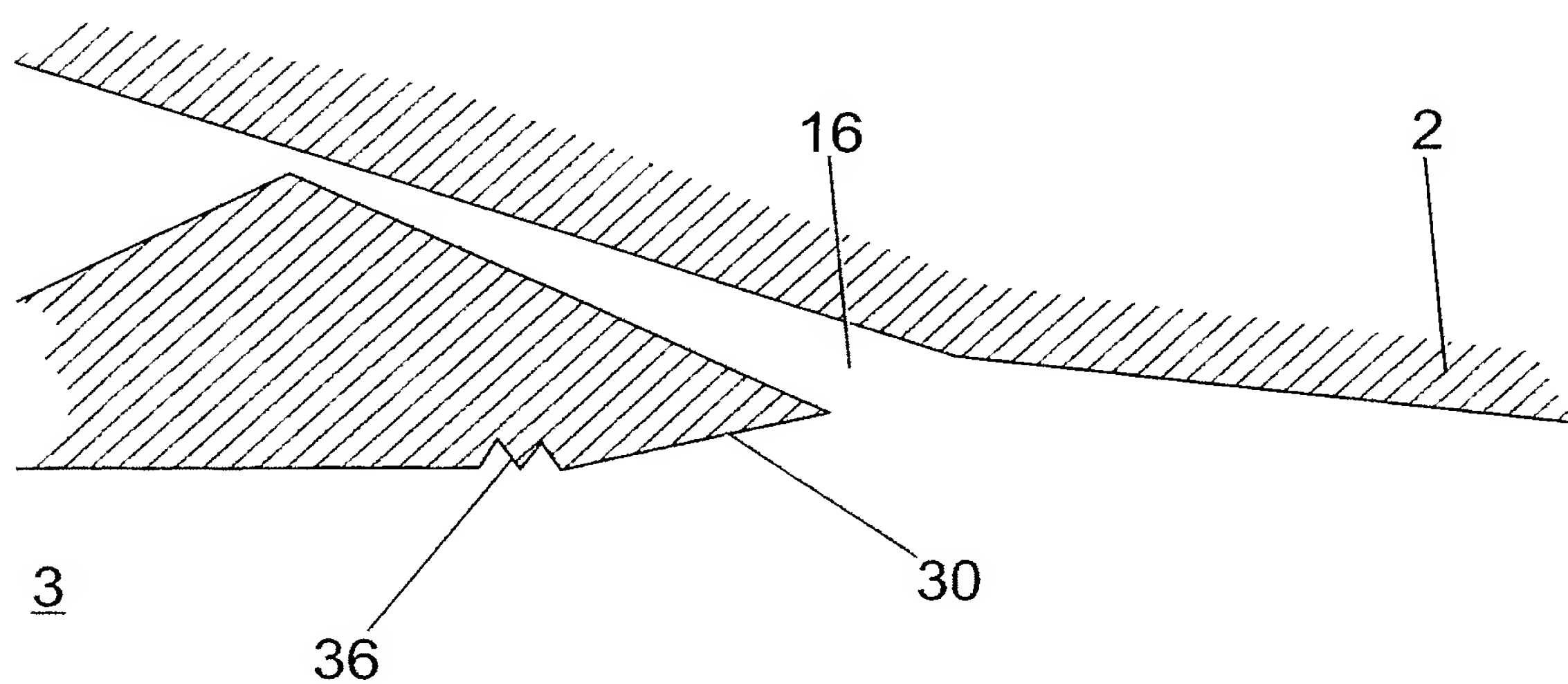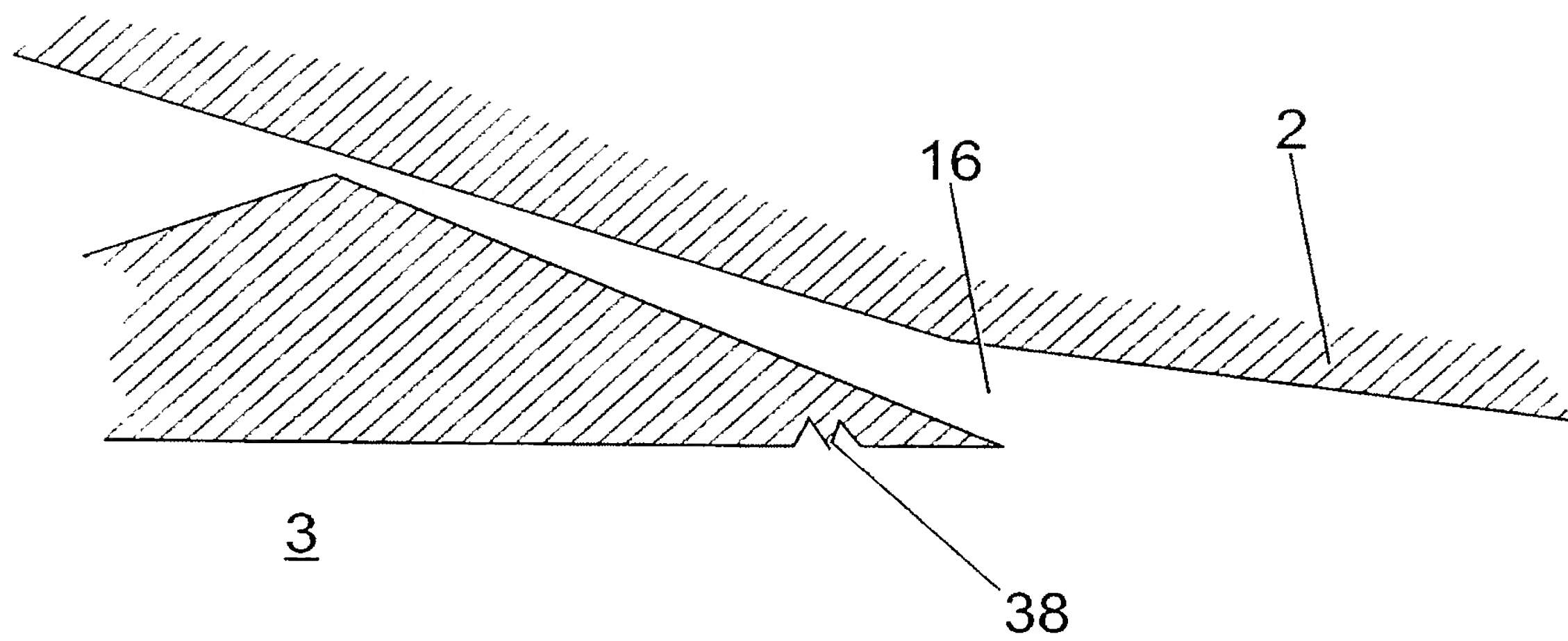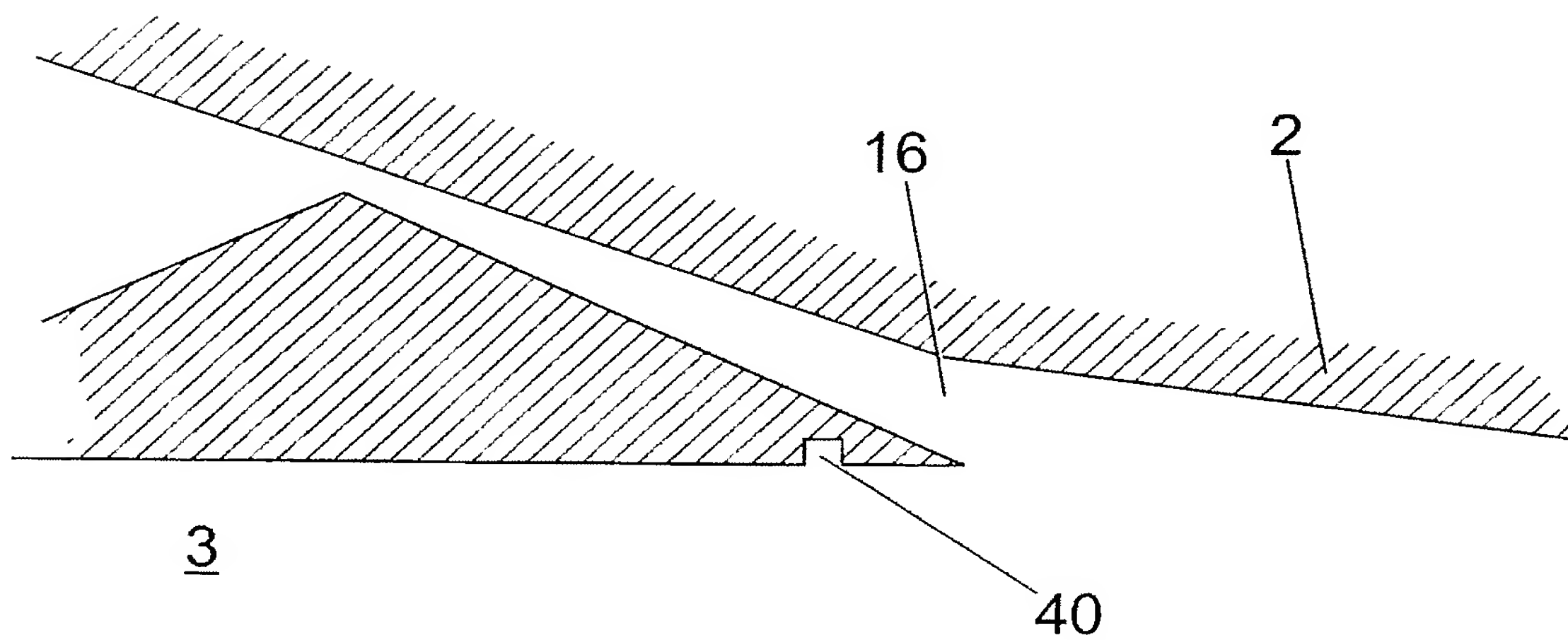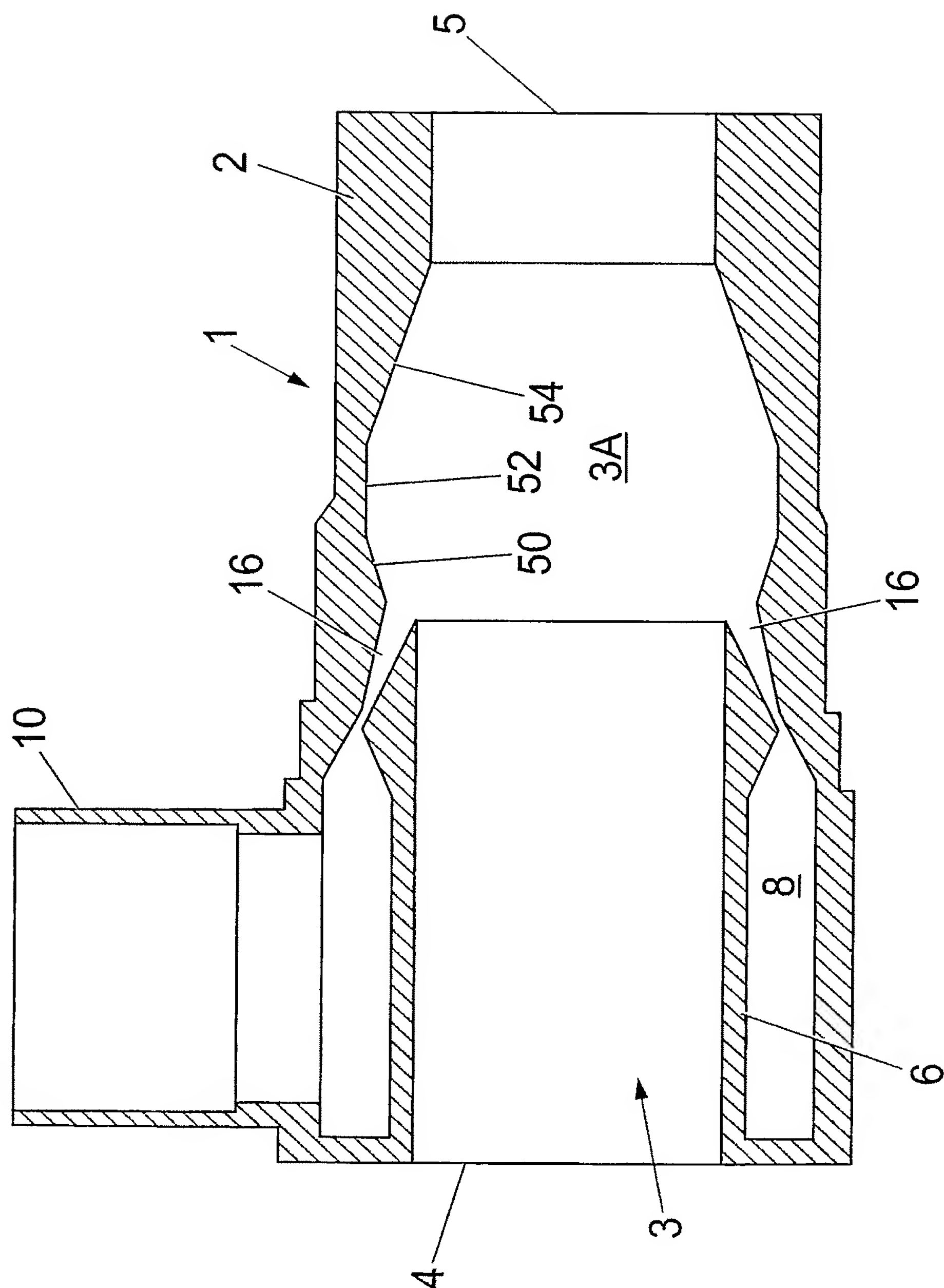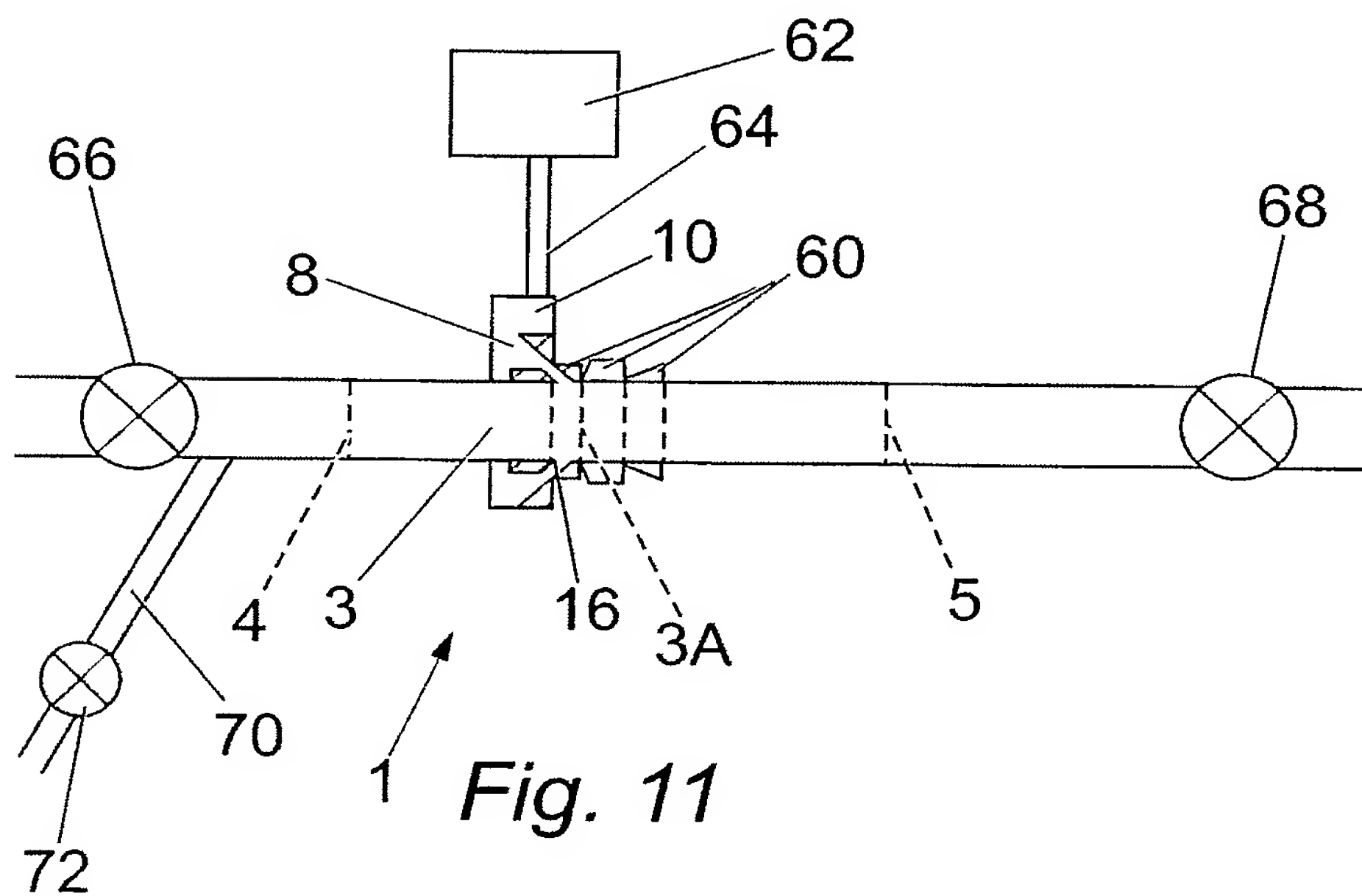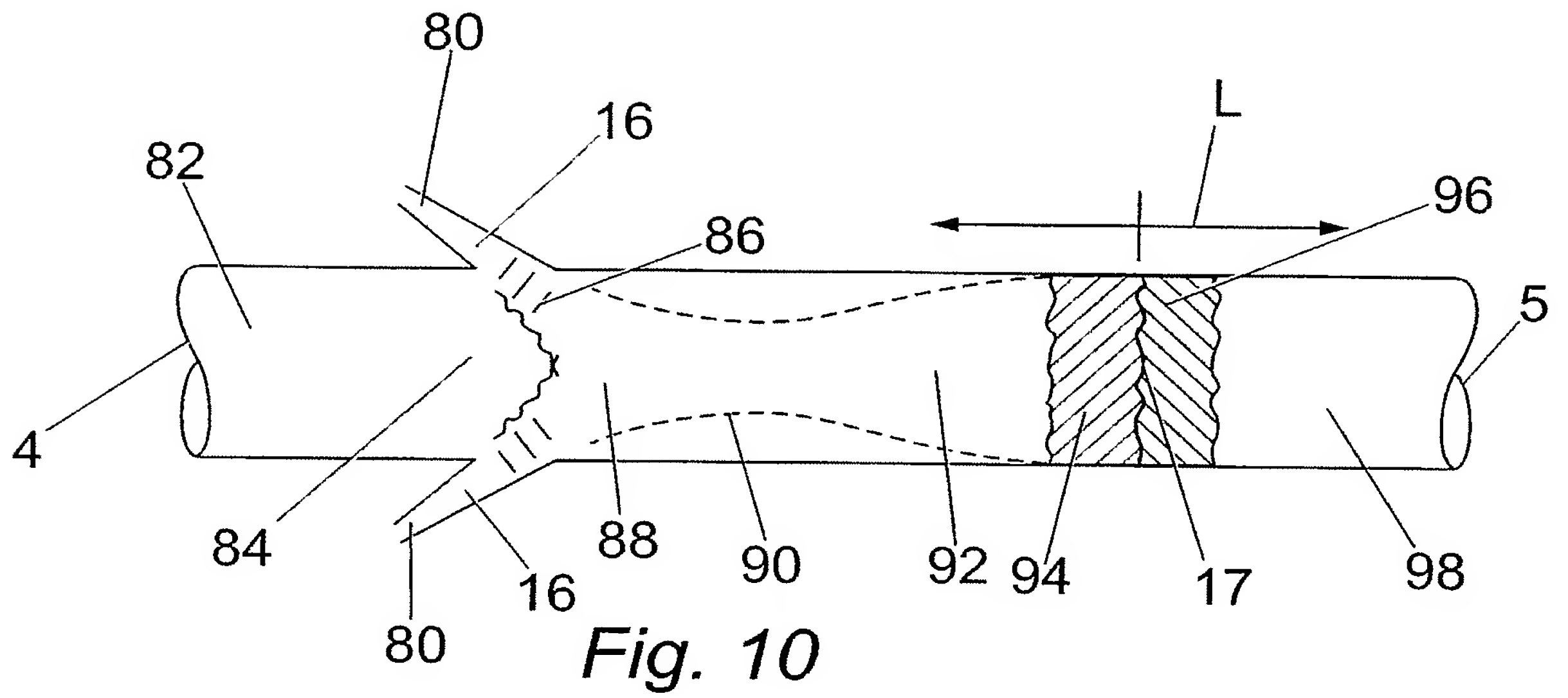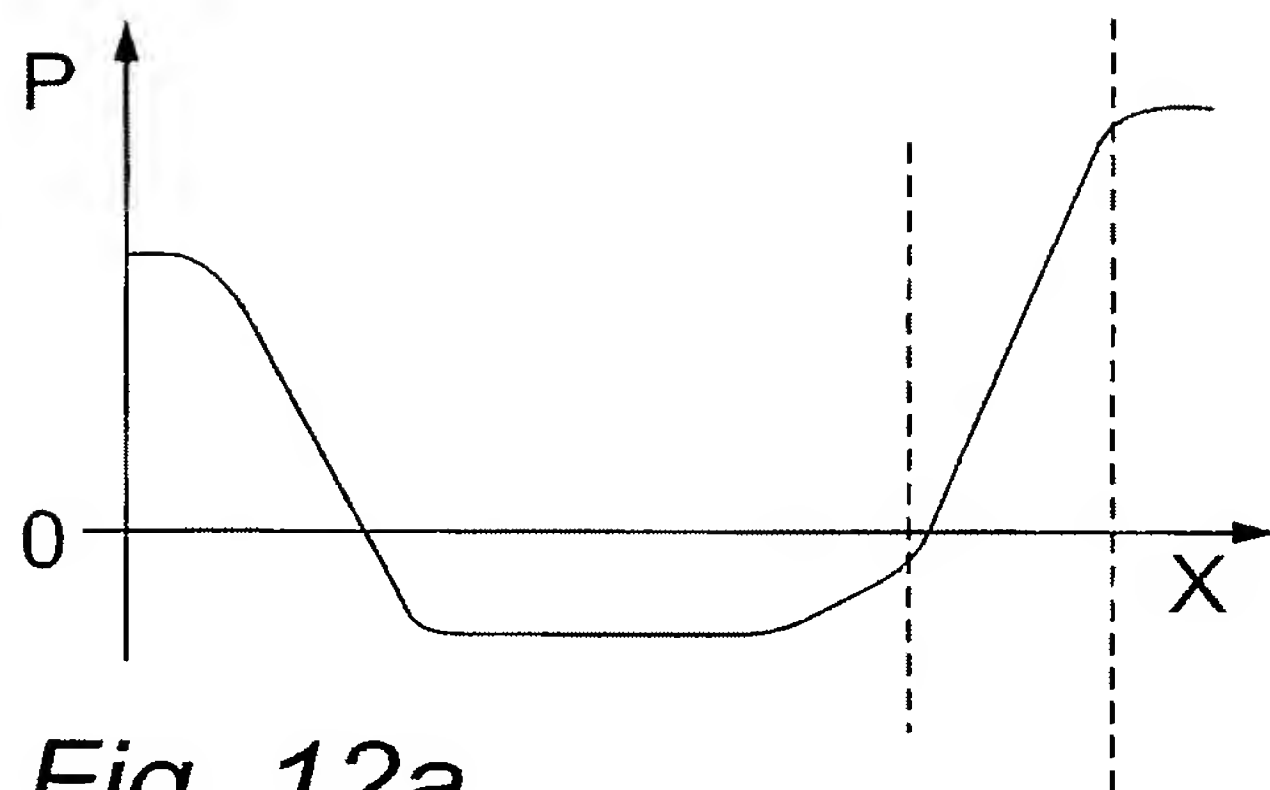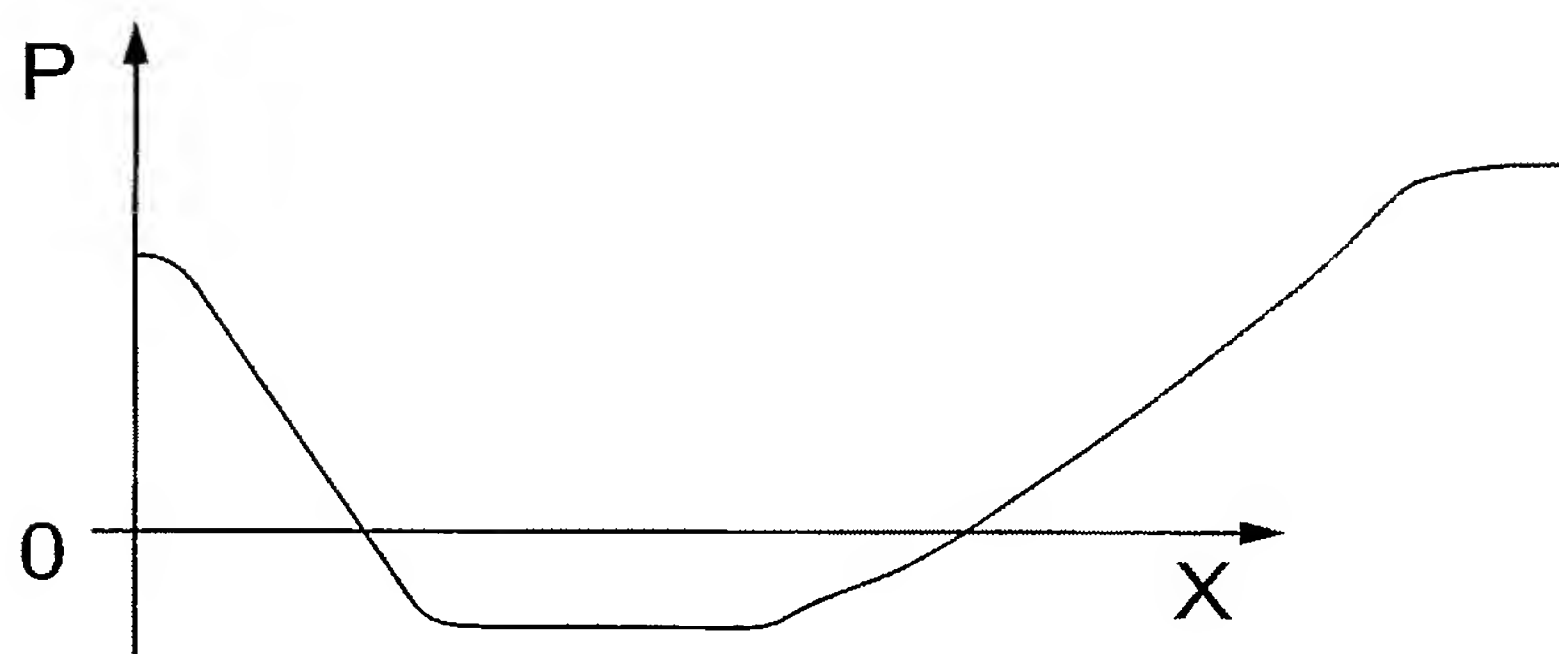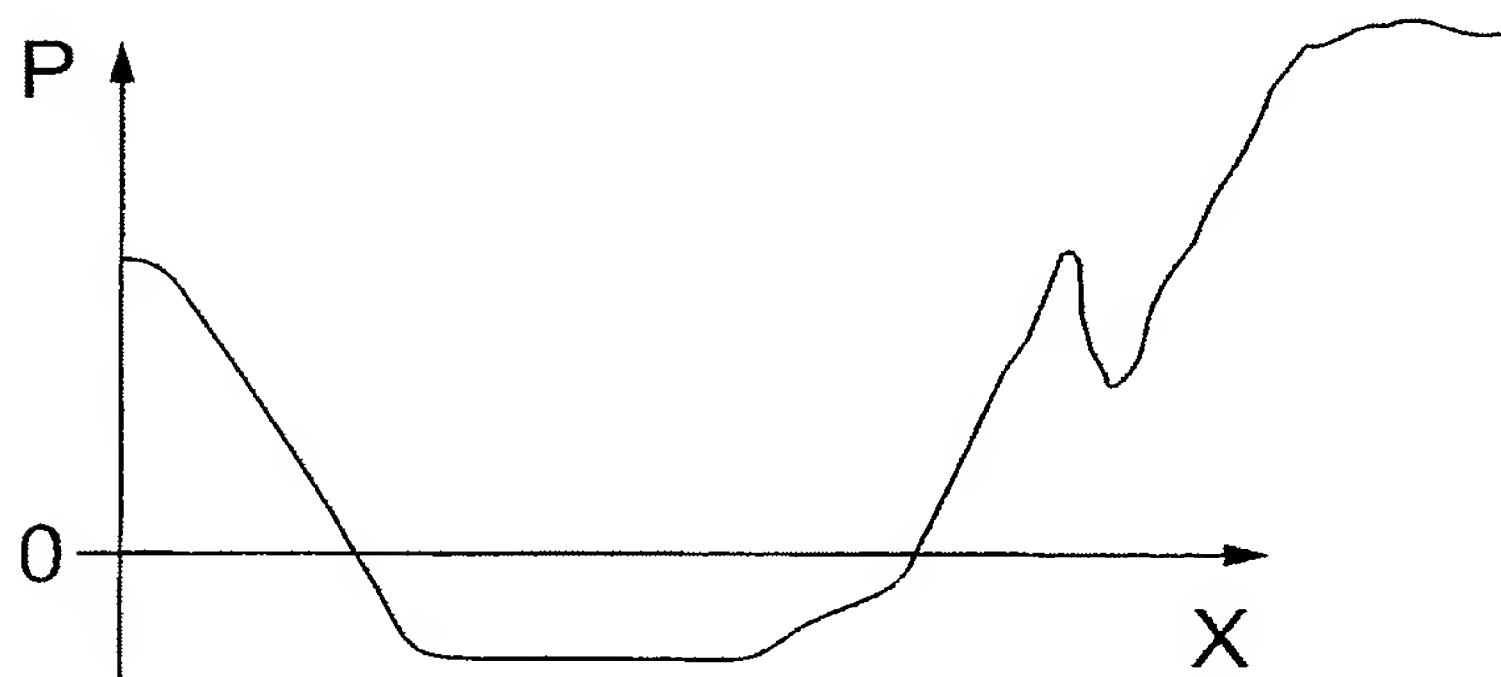
Fig. 12a

Fig. 12b

Fig. 12c
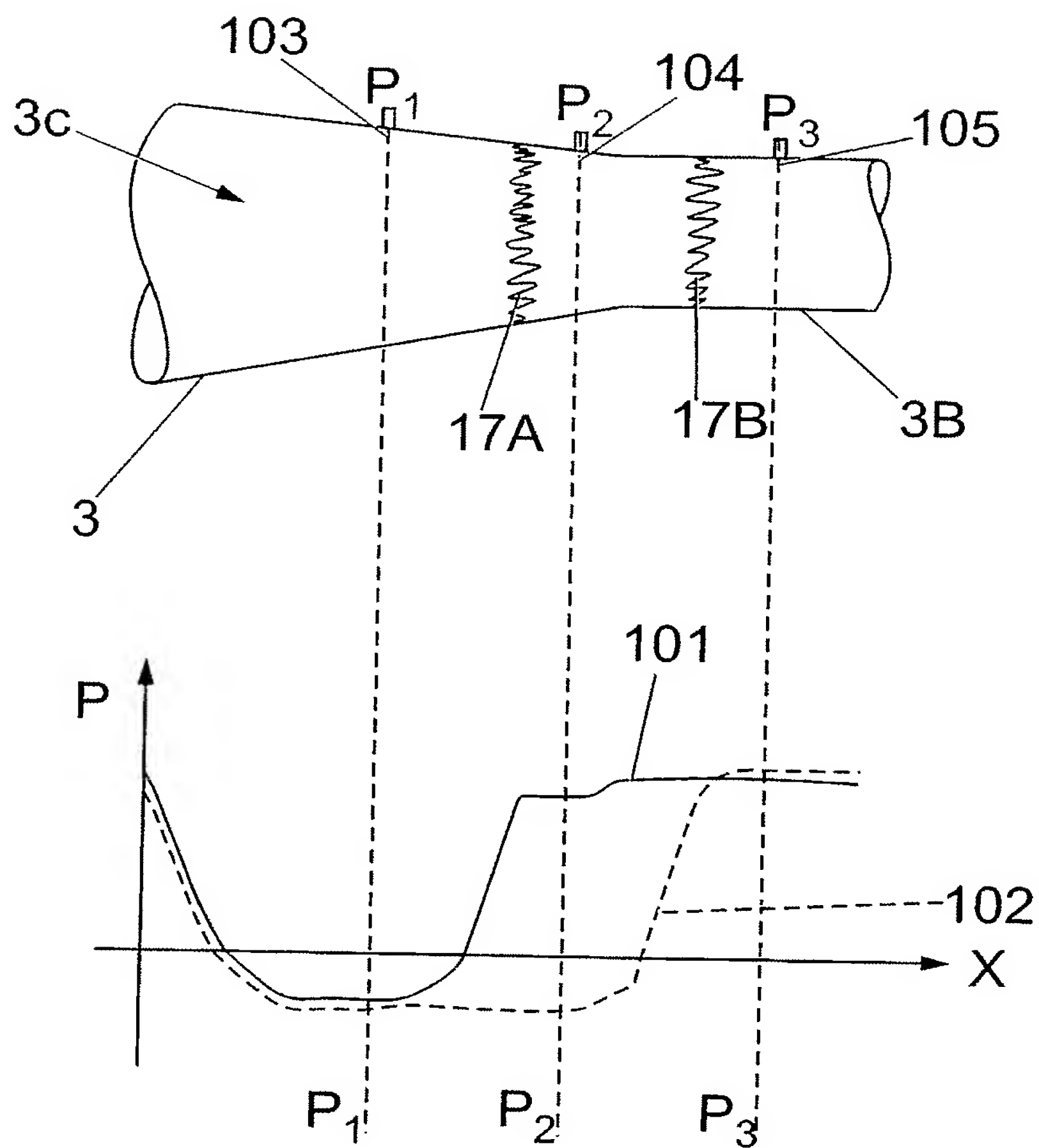
Fig. 13
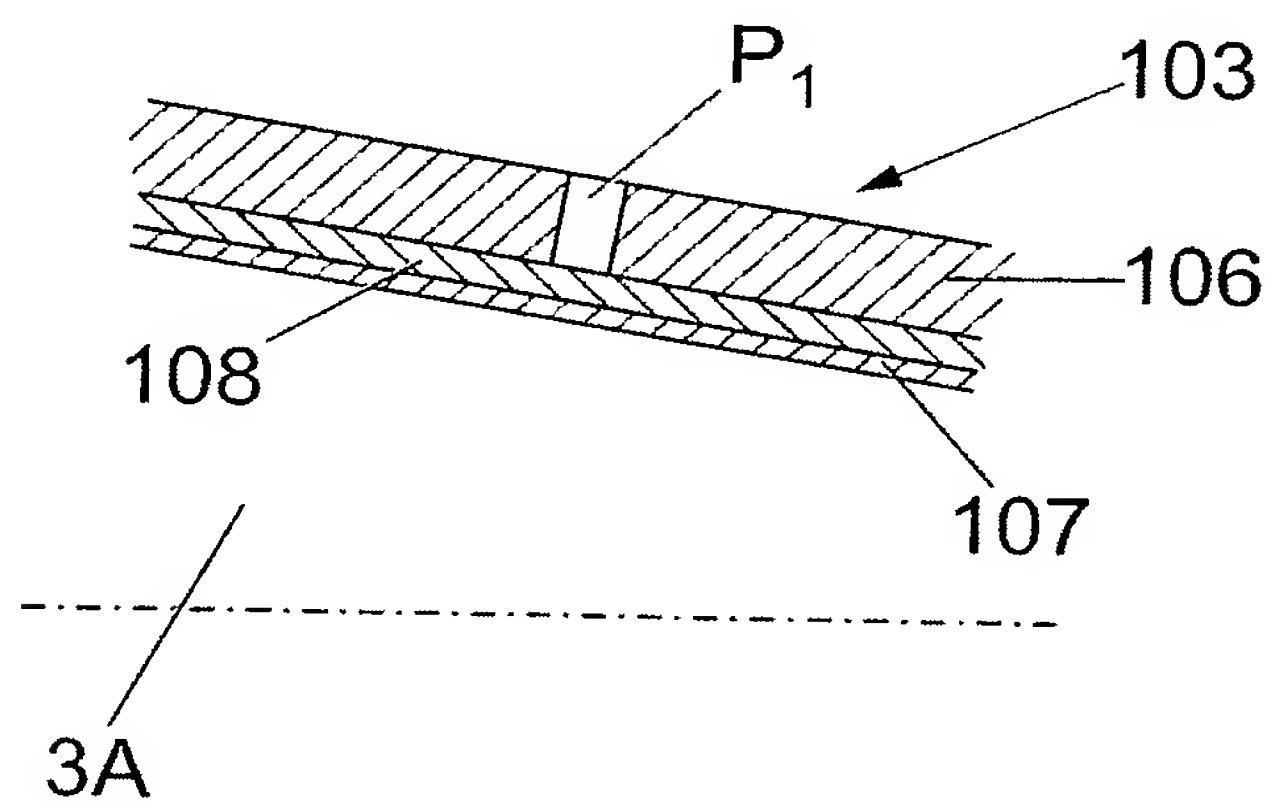
Fig. 14a
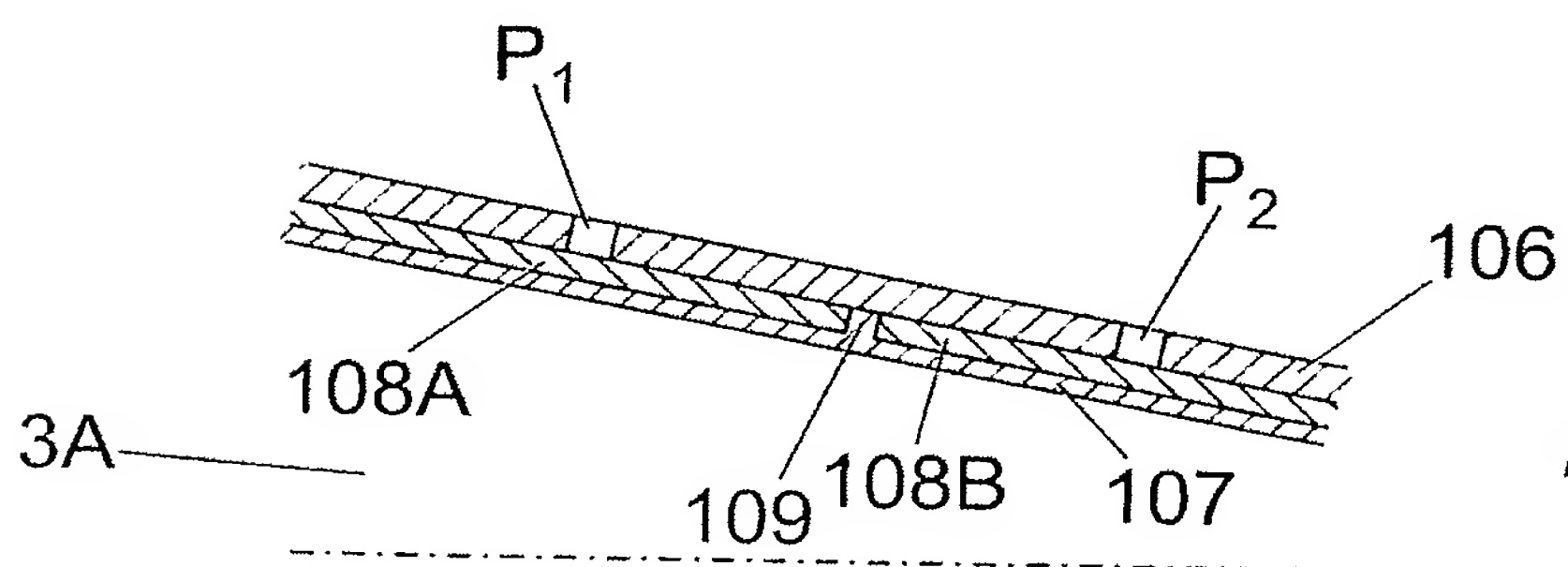
Fig. 14b

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   F04F5/46   F04F5/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   F04F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	GB 2 313 410 A (IAN * STEPHENSON; DONOVAN GRAHAM * ELLAM) 26 November 1997 (1997-11-26)	1,5,6
A	abstract page 7, line 18 - page 10, line 31 figures 1-5	7,11,12
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| X | Further documents are listed in the continuation of box C. | | X | Patent family members are listed in annex. |

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Date of the actual completion of the international search	Date of mailing of the international search report
31 October 2005	10/11/2005

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Kolby, L

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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